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Workshop Proceedings of the 3rd International Workshop

Thin Films in the Photovoltaic Industry

22/23 November 2007

Editor: Arnulf Jäger-Waldau

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Contact information
Address: Dr. Arnulf Jäger-Waldau, Via E. Fermi 2749, TP 450, 21027 Ispra (VA), Italy
E-mail: arnulf.jaeger-waldau@ec.europa.eu
Tel.: +39 0332 78 9119
Fax: +39 0332 78 9268

http://ie.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

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Workshop Proceedings of the

3rd International Workshop

Thin Films in the Photovoltaic Industry

held at the EC JRC Ispra, 22/23 November 2007

Chairperson: Bernhard Dimmler and Arnulf Jäger-Waldau

Editor: A. Jäger-Waldau

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PREFACE

This are the minutes of the 3rd International Workshop "Thin Films in the Photovoltaic Industry" held at the European Commission's Joint Research Centre in Ispra, Italy on 22/23 November 2007.

The workshop series was initiated in 2005 by Bernhard Dimmler, Würth Solar, Germany and is supported by EPIA and the JRC's Renewable Energies Unit. In the meantime the workshop has established itself as a discussion and brain storming event for the Thin Film PV Industry.

In the past years, the yearly world market growth rate for Photovoltaics was an average of more than 40%, which makes it one of the fastest growing industries at present. Business analysts predict the market volume to increase to € 40 billion in 2010 and expect rising profit margins and lower prices for consumers at the same time.

Today PV is still dominated by wafer based Crystalline Silicon Technology as the "working horse" in the global market, but thin films are gaining market shares. For 2007 around 12% are expected. The current silicon shortage and high demand has kept prices higher than anticipated from the learning curve experience and has widened the windows of opportunities for thin film solar modules. Current production capacity estimates for thin films vary between 3 and 6 GW in 2010, representing a 20% market share for these technologies.

Despite the higher growth rates for thin film technologies compared with the industry average, Thin Film Photovoltaic Technologies are still facing a number of challenges to maintain this growth and increase market shares. The four main topics which were discussed during the workshop were:

- Potential for cost reduction
- Standardization
- Recycling
- Performance over the lifetime

I would like to thank all participants for their devotion of time to come to this workshop and share their views in open discussions. It is my strong believe that this workshop series with its fruitful exchange of ideas can accelerate the development and manufacturing capabilities of thin film technologies.

Ispra, February 2008

Arnulf Jäger-Waldau
Renewable Energies
European Commission – Joint Research Centre

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LIST OF PARTICIPANTS

- FACHRI ATAMNY
  OC Oerlikon Balzers AG; Iramali 18; 9496 BALZERS (Liechtenstein)
  tel: +4233884309; fax: +4233885421 ;E-mail: fachri.atamny@oerlikon.com
- MARKUS BECK
  Solyndra, Inc.; 47700 Kato Road ; 94538 FREMONT (United States of America)
  tel: +1-510-440-2555; fax: +1-510-440-8342; E-mail: markus.beck@solyndra.com
- WERNER BERGHOLZ
  E-mail: w.bergholz@jacobs-university.de
- TORSTEN BRAMMER
  Brilliant 234. GmbH; Sonnenallee 7-11; 06766 THALHEIM (Germany)
  tel: +49 3494 66 99 92100; fax: +49 3494 383470; E-mail: j.rott@q-cells.com
- CHRISTOPH DAUBE
  Solar Business Group; Siemensstrasse 100; 63755 ALZENAU (Germany)
  E-mail: christoph_daube@amat.com
- BERNHARD DIMMLER
  Würth Solar; Alfred-Leikam Str. 25; 74523 SCHWÄBISCH HALL (Germany)
  tel: +49 791 94600-301; fax: -109; E-mail: bernhard.dimmler@we-online.de
- EWAN DUNLOP
  European Commission, DG JRC, IE; Via E. Fermi, 2749 ;21027 ISPRA (Italy)
  tel: +39 0332 789090; fax: +39 0332 789268; E-mail: ewan.dunlop@ec.europa.eu
- DAVID EAGLESHAM
  First Solar, Inc.; 28101 Cedar Park Blvd.; 43551 PERRYSBURG (United States of America)
  tel: 4196628500; fax: 4196628525; E-mail: rafoore@firstsolar.com
- DIEGO FISCHER
  VHF-Technologies SA; Av. du Sport 26; 1400 YVERDON (Switzerland)
  E-mail: diego.fischer@flexcell.ch
- DANIEL FRAILE
  EPIA; Rue d'arlon 65; 1040 BRUSSELS (Belgium)
  tel: +3224001062; E-mail: pol@epia.org
- ARNULF JAEGER-WALDAU
  European Commission, DG JRC, IE; Via E. Fermi, 2749; 21027 ISPRA (Italy)
  tel: +39 0332 789119; fax: +39 0332 789268; E-mail: arnulf.jaeger-waldau@ec.europa.eu
- GERT JAN JONGERDEN
  Helianthos; Velpwerweg 76; 6828 BM ARNHEM (Netherlands)
  tel: +31 26 366 2265; fax: +31 26 366 5464; E-mail: gertjan.jongerden@nuon.com
- DR. MICHAEL LIEHR
  Leybold Optics Dresden GmbH; Zur Wetterwarte 50 Haus 303; 01109 DRESDEN (Germany)
  tel: 00493518669558; fax: 00493518669517; E-mail: michael.liehr@leyboldoptics.com
- HANS LINDEN
  Scheuten R&D BV; P.O. Box 22; 5900 AA VENLO (Netherlands)
  tel: +31(0)773599222; fax: +31(0)773247505; E-mail: hlinden@scheuten.com

- HERMANN MAURUS
  SCHOTT Solar; Hermann-Oberth-Str. 11; D-85640 PUTZBRUNN (Germany)
  tel: +49 89 46 264 201; fax: +49 89 46 264 209; E-mail: hermann.maurus@schott.com
- PAUL MOGENSEN
  Avancis.GmbH; Otto Hahn Ring 6; 81739 MUNICH (Germany)
  tel: +49 89 219620 544; fax: +49 89 219620 503; E-mail: paul.mogensen@avancis.de
- HARALD MUELLEJANS
  European Commission, DG JRC, IE: Via E. Fermi, 2749; 21027 ISPRA (Italy)
  tel: +39 0332 789301; fax: +39 0332 789268; E-mail: harald.muellejans@ec.europa.eu
- AXEL NEISSER
  Sulfurcell Solartechnik GmbH; Barbara-McClintock Straße 11; 12489 BERLIN (Germany)
  tel: +49 30 6392 3823; fax: +49 30 6392 3844; E-mail: neisser@sulfurcell.de
- HEINZ OSSENBRINK
  European Commission, DG JRC, IE; Via E. Fermi, 2749; 21027 ISPRA (Italy)
  tel: +39 0332 789196; fax: +39 0332 789268; E-mail: heinz.ossenbrink@ec.europa.eu
- CHRISTOS PROTOGEROPOULOS
  RENI - Renewable Energy Innovations; 170, Sygrou Av.; 176 71 ATHENS (Greece)
  tel: +30 21 09516201; fax: +30 21 09537084; E-mail: c.protogeropoulos@reni.gr
- TONY SAMPLE
  European Commission, DG JRC, IE; Via E. Fermi, 2749; 21027 ISPRA (Italy)
  tel: +39 0332 789062; fax: +39 0332 789268; E-mail: tony.sample@jrc.it
- PETER SCHNEIDEWIND
  ersol Solar Energy AG; Wilhelm-Wolff-Str. 23; 99099 ERFURT (Germany)
  tel: 0361-21951101; E-mail: peter.schneidewind@ersol.de
- RAYMUND SCHÄFFLER
  Würth Solar GmbH & Co KG; Alfred-Leikam-Str. 25; 74523 SCHWÄBISCH HALL (Germany)
  tel: +49 (0)791 94600 308; fax: +49 (0)791 94600 309; E-mail: raymund.schaeffler@we-online.de
- KARL-HEINZ STEGEMANN
  Signet Solar GmbH; Hermann-Reichelt-Str. 3; 01109 DRESDEN (Germany)
  tel: +49(0)3518923156; fax: +49(0)3518923151; E-mail: khstegemann@signetsolar.com
- RALF WENDT
  Calyxo GmbH; OT Thalheim, Sonnenallee 1a; 06766 BITTERFELD-WOLFEN (Germany)
  tel: +49 3494 368 980 130; E-mail: A.Mueller@calyxosolar.com
- UDO WILLKOMMEN
  VON ARDENNE Photovoltaik GmbH&Co.KG; Plattleite 19/29; 01324 DRESDEN (Germany)
  tel: +493512637800; fax: +493512637786; E-mail: willkommen.udo@vonardenne.biz
- WILLEM ZAAIMAN
  European Commission, DG JRC, IE; Via E. Fermi, 2749; 21027 ISPRA (Italy)
  tel: +39 0332 785750; fax: +39 0332 789268; E-mail: willem.zaaiman@jrc.it

AGENDA

22 November 2007

10:00 – 12:00	Optional Laboratory visit of the European Solar Test Installation (ESTI)
14:00 – 14:10	Welcome, Heinz Ossenbrink, European Commission; DG JRC
14:10 – 14:20	Introduction, Bernhard Dimmler, Würth Solar GmbH&Co. KG
14:20 – 14:40	Overview about Thin Film Photovoltaics Worldwide, Arnulf Jäger-Waldau European Commission; DG JRC
14:40 – 15:10	Aspects of Cost Reduction with Large Area Production of a-Si Based Thin Film Modules Christoph Daube, AMAT
15:10 – 15:40	Solar Technology Drivers: Costs / Standardisation, Fachri Atamny, Oerlikon Solar
15:40 – 16:10	Challenges for Vacuum System Manufacturers in the PV Industry Michael Liehr**,** Leybold Optics
16:10 – 16:30	**Coffee Break**
16:30 – 17:00	Thin Film Photovoltaic Production Technology Udo Willkommen, von Ardenne Photovoltaik
17:00 – 19:00	short presentations of each manufacturing company
20:00	**Dinner**

23 November 2007

08:30 – 09:30	continuation of company presentations
09:30 – 10:00	PV Cycle – Introduction, Daniel Fraile Moronto, EPIA
10:00 – 10: 30	PV Cycle – Technical Issues, Raymund Schäffler, Würth Solar
10:30 – 11:00	**Coffee Break**
11:00 – 11:15	Standardization: what have been already and what should be done from the sight of EPIA, Daniel Fraile Moronto, EPIA
11:15 – 12:30	How can a New and Emerging technology as Thin Film PV Profit from Standardisation, s Werner Bergholz, Jacobs University, Bremen
12:30 – 14:00	**Lunch**
14:00 – 14:30	IP-Performance Project, Daniel Fraile Moronto, EPIA
14:30 – 15:30	Current Situation of International PV Standards, Ewan Dunlop, Europan Commission – DG JRC
15:30 – 16:00	***Conclusion and Close of the Workshop***

EXECUTIVE SUMMARY

Introduction

After the success of the two previous workshops on Thin Films in the Photovoltaic sector, in November 2005 and November 2006 respectively there was a big demand for the follow-up. Therefore, the 3rd International workshop on Thin Films in the Photovoltaic sector was held in Ispra, Italy, the 22nd &23rd November 2007. The workshop was chaired by Bernhard Dimmler of Würth Solar and Arnulf Jäger-Waldau of the European Commission, DG JRC. The organization was supported by EPIA (European Photovoltaic Industry Association) and hosted by JRC Ispra, Italy.

The results of this workshop are an important input for the Working Group "Science, technology, industry and application" of the PV Technology Platform, as well as for the EU Integrated project Performance and the recently founded association PV CYCLE which aims to create an European PV waste management system in order to collect and recycle PV modules.

Due to the fact that the Thin Film Industry is growing rapidly and a large number of new players are entering the field with announcements of new factories which are targeted to double in capacity each year, a targeted discussion workshop is needed.

Background

Photovoltaic solar electricity systems do have the potential to deliver electricity on a large scale at competitive cost in the near future. One of the main obstacle of PV today to serve as an important energy source is the high production cost of the PV module. Today PV is dominated by wafer-based Crystalline Silicon Technology as the "working horse" in the global market (more than 90% share of the market in 2006). Thin Film technologies have the highest cost reduction potentials of all PV technologies in the mid and long term. The currently used thin film materials are amorphous / microcrystalline Silicon and the compound polycrystalline semiconductors CdTe and CIS (CIS holds for the material family of $Cu(In,Ga)(Se,S)_2$). All of them are developing fast and are already in the status from small startups to large scale productions.

The disadvantage of Thin Films Technologies in comparison to Crystalline Silicon Technologies is still the lack of fundamental material property data (at least for CdTe and CIS) and the missing maturity in production technology.

This workshop was aimed to increase the support to concentrate efforts on a common level. The aim was to strengthen and increase the share and the role of thin films technologies in the worldwide PV market for the future.

Topics of the Workshop

The topics which are of high interest for the Thin Film manufacturers were addressed during the workshop; these are mainly the reduction of production cost and the performance and reliability of the product over a long lifetime. Besides other topics of high relevance that have gained importance during the last years were addresses and are also presented in the next list:

Potential to reduction cost:

- Consumption of materials
- Increase of the module efficiency
- Bigger deposition areas
- Economies of scale

Standardization:

- of the final product (size, materials, etc.)
- Manufacturing process (sputtering techniques, substrates used, equipment interfaces, etc.)
- Integration in building.

Recycling:

- Adaptation to the European legislation.
- Introduction of a take back and recovery system of PV modules in Europe.
- Different techniques for recycling.
- Cost of collection and recycling of thin films modules vs. crystalline silicon modules

Performance over the lifetime:

- taking advantage of the c-Si technology long experience.
- Behavior and degradation of materials.
- Characterized of the thin film module by measuring the electric performance in simulated sun light compared to outdoor behavior.

Further scientific R&D with respect to PV quality and stability and the establishment of professional and standardized characterization equipment and methods under industrial circumstances is highly needed.

The final aim of the workshop was to strength the PV thin film technology and to establish it as a leading technology in the incoming years through minimizing investment and material costs and maximizing product quality and productivity.

For the 3rd International Workshop on Thin Films in the Photovoltaic sector representatives from the emerging Thin Film companies, which are already producing or will start next year, representatives for equipment manufacturers of in-line productions as well as experts in the field of standardization, testing and certification and recycling were invited to participate.

Expectation of the organizers

For the further support and to enable Thin Films to become a leading technology in Photovoltaics in general the workshop was designed in order to find answer to the following questions:

- What is the status of Thin films PV?
- What is the status of and which are the technical roadmaps of the vacuum equipment and/or process suppliers?
- What are the technological achievements?
- Are there synergies in fields like glass coating or FPD production?
- What are the potential ways to reduce production cost and how to overcome them?

PROCEEDING OF THE WORKSHOP

Summary of Presentations

Bernard Dimmler, member of the Steering Committee of the EU PV Technology Platform and chairman of the workshop started the meeting with an overview of the Thin Films technology in the PV sector, presenting how the sector has grown in the last few years and the perspective for the coming years, in which the Thin Films Photovoltaic may share around 20% of the global PV market in 2010. The current market situation is very favorable for Thin Films Photovoltaic and this fact is reflected in the fact that not only new market players are choosing this technology as their technology to invest, but that an increasing number of established solar cell producers with previous focus on wafer based solar cells are broadening their solar cell production basis with thin films technology.

The capacity of the Thin Films is rapidly increasing and by the end of the decade roughly 2 to 3 GW of production capacities for various thin films technologies are expected.

Today there are still some weak points that must be address in the Thin Films technology:

- No sufficient knowledge in basic material (at least for CdTe and CIS)
- Maturity of production technology still low, prototype equipment
- No standards in manufacturing and product up to now
- Not sufficient knowledge in how to measure the different thin films technologies with the same accuracy than for crystalline silicon modules

Nevertheless, the Thin Films PV technology presents several advantages as for example:

- high product quality, and a potential module efficiency of 15-20% in the mid/long term
- low material consumption with a solar cell thickness of about 2-5 µm
- Huge flexibility in module design (material costs)
- low energy needs with an energy pay back time ≤ 1.5 years today and ≤ 0.5 year for the long term
- high energy ratings in application
- High production depth (from raw material to end product)

Furthermore, the Thin films PV have the highest cost reduction potential of all PV technologies. This reduction will be achieved by:

- reduction of material consumption (the 50% of the final module cost is due to the material cost)
- Introduction of new standards for manufacturing and products
- Increase of the deposition areas (in both glass and rolled foils)
- Recycling of the module materials (glass represent from 75%-90% of material of whole module)

The next presentation was given by Arnulf Jäger-Waldau, of the EU DG JRC, in which a status and perspectives of Thin Film solar cell production was presented. With a production of cell/modules of 2.5GW in 2006, the announced capacity by the PV companies for 2010 is 23GW, of which Thin Films PV are 6GW (note that this figures may differ about 50% with the real capacity). Within Thin films, a-Si seems to be the most deployed technology followed by CIS and CdTe. Europe is leading and will lead the deployment of the Thin Films technologies during the next years, followed by USA (focused more in CIS), Japan and China (where more than the 95% of the production will be of a-Si). If production volume is ramped up according to plans, Thin Film PV has the potential to reach the 1 €/Wp cost target at the end of this decade.

The system‘s component costs were analyzed in order to identify how is the best way to reduce the whole cost of the system:

- Planning &financing: 15%
- Inverter: 9-10%
- BOS &installation: 10-30%
- Modules: 40-66%

An increase or decrease of the efficiency of the module implies an increment or a reduction of the BOS &installation costs respectively. Nevertheless, the financing and inverter cost remain always the same. Therefore, a way to reduce cost would be the use of lower efficiency modules in those cases in which the value of the installed area is not relevant.

Then, the event was divided in five sessions:

- Equipment manufacturers
- Thin Films module manufacturers
- Recycling (PV CYCLE)
- Standardization
- IP Performance

Session 1: Equipment manufacturers

Four presentations were given during this session. Each company (Applied Materials, Oerlikon, Leybold Optics, VonArdenne) presented their own products, technologies, roadmaps and arguments on how the production cost could be reduced. The presentations can be found in the annex.

The discussions of these presentations were focus mainly on:

- Reduction of the production cost by:
    - Reducing the cost/m^2: increasing the substrate area (following the experience of the LCD industry) from 0.6m² to 10m². These big areas may give an added value to PV from the architects’ point of view (increasing the BIPV market and applications).
    - Increasing W/m²: using high efficiency technologies like the tandem μc-Si/a-Si.
    - Reducing de number of steps in the manufacturing process and the number of this process. There are too many processes established or still under development: PECVD, MOCVD, (co)-Sputtering, (co)-Evaporation, Paste, Inkjet, Electroplating, Nanoparticle/Sol-Gel etc.
    - Reducing energy consumption in the factories.
    - Increasing the capacity of the factories (mass production)

- Standardization of glass substrate size: while some equipment manufacturers and module manufacturers find the increment of the substrate size as a driver for reduction of cost production, others affirm that the use a standardized size would help to reduce this cost. The discussion comes when defining which the most appropriate size is.

- The use of a (dual) Cylindrical Sputter Magnetron instead of a Planar Sputter Magnetron will Increase the utilization of the target material (from ≤ 45% to ≤ 80%) and therefore, will reduce material costs in about 40%. And, although the price of the cylindrical sputter magnetron is almost the double than the planar one, the lifetime is longer (up to 3 times more)

Session 2: Modules Manufacturers

For this session 13 Thin Films PV companies (Solyndra, Brilliant, Würth Solar, First Solar, Helianthos/NUON, Scheuten, Schott Solar, Avancis, Sulfurcell, Solar cells Hellas Group, Ersol, Signet Solar, Calyxo)which are already producing or will start next year and represent the different Thin Film technologies as silicon based, CIS and CdTe gave a short presentation. Each company presented (with and without slides) their current and expected production capacity, the manufacturing process, product characteristics as efficiency, sizes, power, and technological roadmaps. See presentations in the Annex.

The outcome of this session can be summarized in the following:

- Glass substrate size and module size don't need to be the same. And depend on each module manufacturer how to use this substrate (how many modules per substrate are necessary in order to avoid material losses)
- It is not clear the benefit of G8.5 versus G5 (while bigger substrates will reduce production cost, the cost for packaging, transportation and the difficulty in the installation will increase). For the previous reasons, it isn't clear neither the benefit of big modules for BIPV.
- The reduction of €/W has to be addressed at the same time by increasing the production capacity and increasing the efficiency.
- The Standardization of Thin Film Processes and equipment is also required to allow the reduction of production cost. Nevertheless, the current existence of many different modules sizes and many substrates sizes will not help to this standardization process.

Session 3: Recycling

The main topic of this session was the recently creation of PV CYCLE and the activities that association is carrying out. Two presentations were given (See presentation in the Annex), the first one by Daniel Fraile, EPIA, to present the current European policy on waste and the possibility of inclusion PV modules under the scope of the WEEE directive during its revision next year. This, together with the aim of becoming a responsible industry which tackle the climate change and others environmental issues have been the motivations to found the PV CYCLE association. The main objective of PV CYCLE, lead by EPIA, BSW and the main international PV companies, is to introduce a Take Back and Recovery system for PV modules in Europe by the end of 2008.

Raymund Schäffler from Würth Solar and also member of PVCYCLE, presented mainly which would be the costs for the PV industry in to possible three scenarios: Business as usual, introduction of the Take back and recovery system with PV under the scope of the WEE directive and without it (intermediate results of a study carried out by Ökopol).

Different studies from NREL, NBL, ZSW and others centers estimate the cost recycling in the range of 5 – 10 c€/Wp. It is important to note that they also estimate that the cost of non-recycling will be much higher due to the disposal of hazardous substances in landfills.

Some weak points related to the cost of recycling of Thin Film PV modules are:

- The highest cost of recycling is the crashing and separation of the active layer from the glass.
- Each Thin Film technology presents different cost of recycling due the material used.

- The current cost of recycling is based in certain assumption, but this cost will decrease with the experience (learning curve).
- With an industry based in the economies of scale in order to reduce the production cost, the quantities of PV waste will increase implying an increase of the cost of Collection & transportation of PV modules.
- The cost of Thin Film PV modules is still more expensive that for c-Si technologies.

Session 4: Standardization

A session was dedicated specially to understand the benefits of the Standardization and how the Thin Film PV and the PV industry in general can profit from it. Two presentations were given during this session. See presentation in the Annex.

Daniel Fraile from EPIA presented the recently created EPIA-SEMI PV Standards Technical Committee which objectives are to identify, develop and implement standards or specifications by the industry for the industry, especially in those fields where other bodies like IEC or CENELEC are not involved, like materials, equipment and processes.

Werner Bergholz from the University of Bremen and also member of SEMI gave a presentation on how the standardization of products, materials, equipment and processes helps to the industry to reduce production and product costs, and how it lowers the entry barriers for competition. Real cases from the Semiconductor and nanotechnology industry were given as good examples on how the standardization can reduce dramatically the production cost in emerging technologies.

Session 5: EC Integrated Project Performance

For the last session of the event, as in the previous edition of the International workshop on Thin Films, the EU IC Performance was presented. Two presentations were given (See presentations in the Annex).

Daniel Fraile, EPIA reported on the objectives, structure and fields of work within the project. The project aims to improve the general understanding of:

- PV device testing methods,
- PV module and systems performance,
- PV module and systems stability.

Ewan Dunlop, EU DG JRC, gave and overview of the IEC TC82 activities and their relation to the Performance Project and its results.

An inter comparability Round Robin among the main European Test Laboratories has been done for PV c-Si modules with the following conclusions:

- Good results regarding comparability: The spread for reported P_{MAX} lies in the range ±2%. High or systematic discrepancies for laboratories could be either explained by deficits of the measuring equipment or measurement procedures.
- PV Industry expressed the need for additional information on calibration data of reference modules. Test reports shall go beyond STC and state how modules shall be measured to ensure an optimal transfer of calibration.

Thin Round Robin is being performed now for Thin Films PV modules and result will be available for spring 2008.

The lifetime and degradation of 204 c-Si modules have been analyzed for 23 years in the JRC; some of the results are the following:

- High power losses (>20%) are attributed generally to FF losses (interconnections resistance increase), while moderate modules degradation is caused by I_{SC} loss due optical properties degradation and photon induced semiconductor degradation,
- There is no statistically significant difference in the performance of the modules with mono-crystalline and poly-crystalline cells (average degradation rate 0.7 % per year),
- There is difference between groups of modules with the glass back substrate (average 23% degradation) and polymer substrate (average 14%),
- The visual appearance of field–aged modules is often not correlated with their electrical performance and state of electrical insulation,
- Of the 204 modules studied in this work 82.4% have been verified to have the final maximum power greater than 80% of the initial power i.e. meeting the manufacturers warranty criteria,
- Furthermore two thirds of modules have the final maximum power verified to be more than 90% of the initial power value after 25 years of outdoor exposure.

Finally B. Dimmler asked the participants to give feedback to the workshop and proposals for topics and areas of interest for possible future workshops. Active support to realize these further activities is highly welcome.

ANNEX: WORKSHOP PRESENTATIONS

The Presentations are also available on the Web-Page of:

http://www.epia.org

http://ies.jrc.ec.europa.eu/refree.html

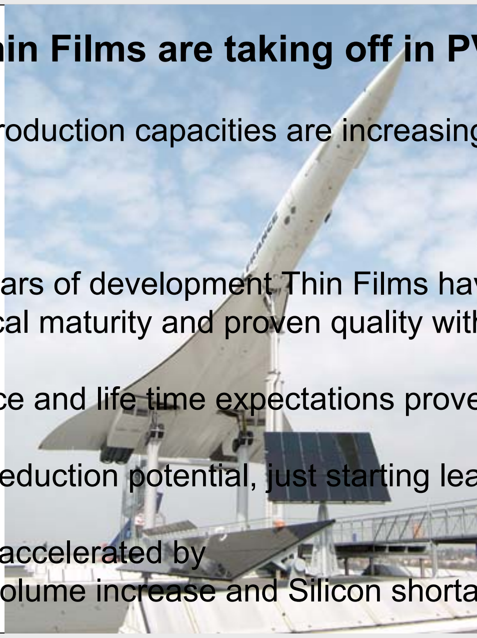
3rd International Photovoltaic Industry Workshop on Thin Films

“Introduction”

Bernhard Dimmler
Würth Elektronik Research GmbH

Schwäbisch Hall
bernhard.dimmler@we-online.de

www.wuerth-solar.de



Thin Films are taking off in PV

“Thin Film production capacities are increasing rapidly“

due to:

- After 25 years of development Thin Films have gained enough technological maturity and proven quality with calculable risk
- performance and life time expectations proven
- High cost reduction potential, just starting learning curve

Additionally accelerated by
PV market volume increase and Silicon shortage

Thin Films in PV

Thin films PV have the highest cost reduction potential of all PV technologies today.

The emerging materials are:
- **amorphous / microcrystalline Silicon**
- **CadmiumTelluride (CdTe)**
- **CIS: Cu(In,Ga)(Se,S)$_2$**

All are starting with several large volume factories with good prospects to reduce costs of PV modules

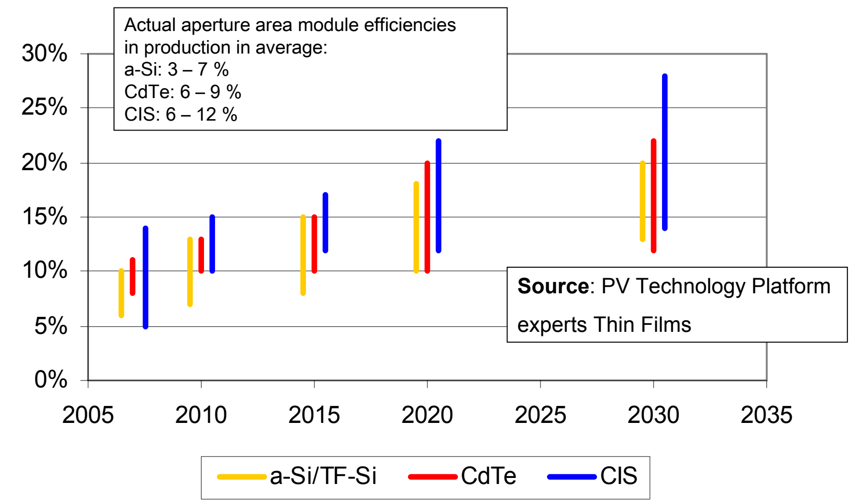
Lacks of thin Film Technologies:

- **Material knowledge (at least for CdTe and CIS) still low**
- **maturity of production technology still low, prototype equipment**
- **no standards in manufacturing and product up to now**

Advantages of Thin Films general aspects

- **high product quality, efficiency**: outstanding CIS
  CIS: cell max. 19,9 %; module 11 up to 14% today,
  potential module efficiency 15-17% in mid/long term
  CdTe and a-Si: 2 – 4 % less respectively
- **low material consumption:** solar cell thickness 2 - 5 µm
  further huge potential esp. in module design (material costs)
- **low energy needs:** energy pay back time: today ≤ 1.5 years,
  long term ≤ 0.5 year
- **high energy ratings in application**

Module Efficiency
Expectation of maximum values



EU-JRC
3rd International Photovoltaic Industry Workshop
on Thin Films
EPIA

Advantages of Thin Films in production
"large area production technology"

- **in-line continuous and large area deposition**
  - **glass: 0.6 x 1.2** → 1.4 x1.4 → 3.2 x 6.0 m^2
    synergies with architectural glass coating and FlatPanelDisplay technologies
  - rolled foils (metal and polymer) of 30cm x km: synergies packaging ind.
- **low process temperatures :** ~ 500°C for CIS/CdTe, all other processes < 200°C
- **Integrated electrical interconnects**
- **High production depth: from the raw material to the final product**
  high grade of automation, high yield

→ **high cost reduction potentials**

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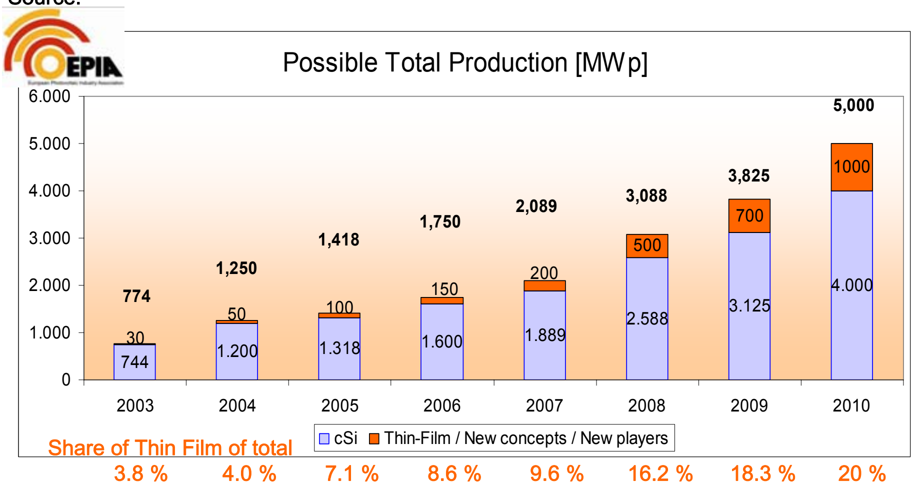
Module Production

c-Si, Thin Film as estimated by end of 2006

Source:



Estimation: 2020 thin films 7.5 GW (=22%) of total 34 GW,
2030 thin films 133 GW (= 28.6% = new concepts) of total 380 GW

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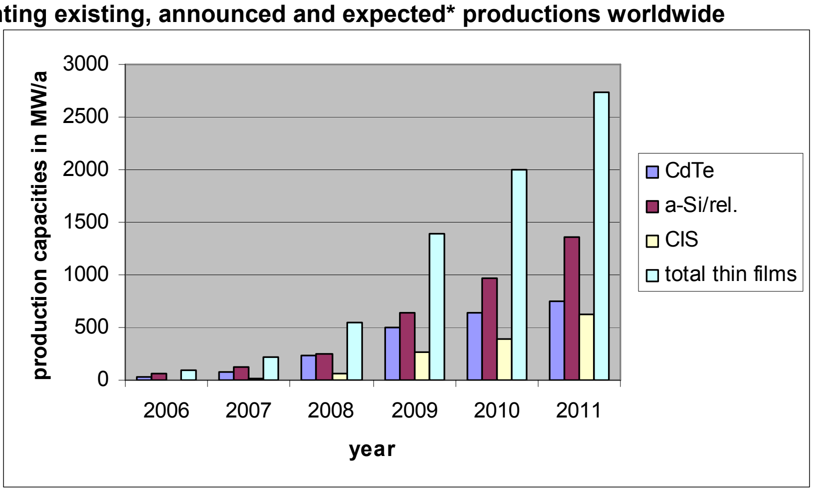
Expected Evolution of Thin Film Module Production Capacities (as of Oct. 2007)

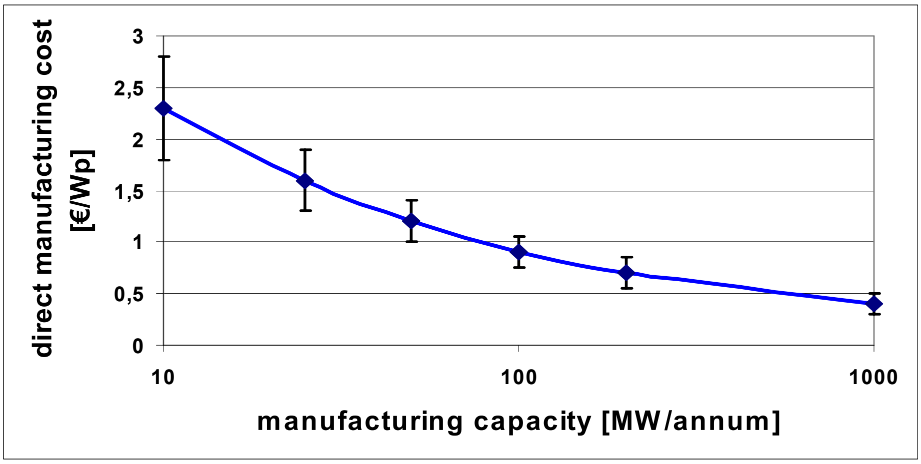
counting existing, announced and expected* productions worldwide



•expected: assessment of technological maturity by the author

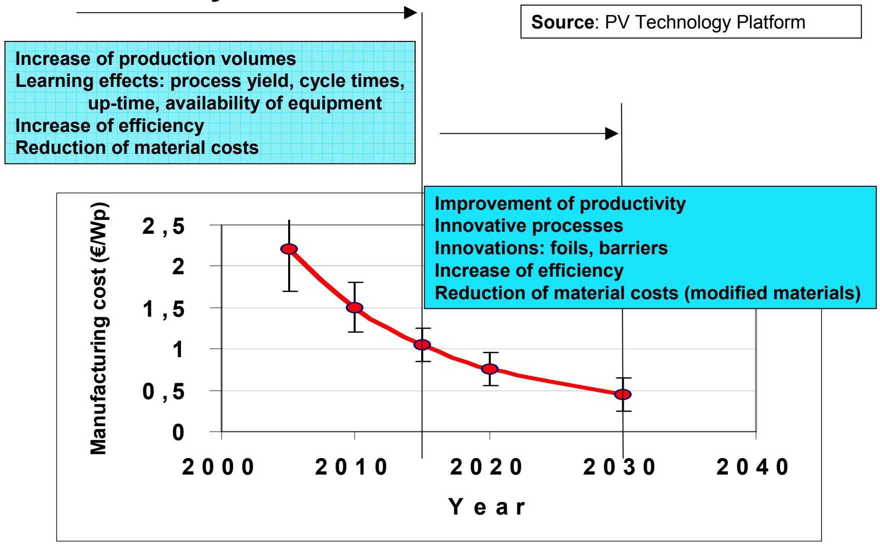
Manufacturing costs:
Driven by production volume

Source: PV Technology Platform experts Thin Films



Manufacturing costs:
Driven by innovations

Source: PV Technology Platform



Thin Films: cost compete with quality
Two main routes of development

In the mid future there will be 2 types of products of Thin Films:

1) Very low cost, low quality:
- Very large substrates based on glass:
  from square-meter to 20 m² (see FPD or architectural glass)
- Foils of km´s lenght, roll-to-roll coating + sealing barriers
- Innovative deposition processes vaccum less like electrodeposition and printing of nanoparticles, glass beads, etc.

2) Mid cost, very high quality:
- Larger area, high productivity
- Application and transfer of in laboratory already proven technologies
- Monolithic integration, series interconnect, hermetic sealing
- New concepts: multitjunction, spectrum conversion, modified materials

Improvements in Production
Technological Roadmap
COST REDUCTION

Product quality : average module efficiency
by continuous process optimization, stabilization and innovations

Productivity: - improvement of overall process yield:
by continuous process optimization and improved process control

- reduction of cycle time,

- increasing product area in production

- standardization in production

Materials: reduction amount of material (yield, thickness),
recycling of production waste, EOL module recycling
longer term: new module concepts (foils)

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3rd International Photovoltaic Industry Workshop on Thin Films

	Thursday 2007-11-22	
14:00	Welcome	tbc Heinz Ossenbrink
14:10	Introduction	Bernhard Dimmler
14:20	TF international overview	Arnulf Jäger-Waldau
Topic 1: ~ 14:30-18.30h	**Scaling Effects on ROI, Glass (foil) size in production** How are the status and the technical roadmaps of the vacuum equipment and/or process suppliers? Are there synergies from the glass coating or FPD production or other fields? What are feasible sizes? With what steps of glass (foil) size there could be an optimum in gain of ROI and low productivity risk? How yield and availability could be influenced? Etc.	
30min.	Applied Materials	
30min.	Oerlikon	
30min.	Leybold Optics	
30min.	vonArdenne	
5-10min. each	short presentations of each manufacturing company if possible with roadmaps with respect to scaling, glass size, state of the art and future, etc.	
19:30	*Dinner organized by EPIA*	

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	Friday 2005-11-23	
Topic 2 ~ 9-10.30h	**PV-Cycle:** presentation of the activities going on in this topic, ongoing plans	
15 min.	PV Cycle: history and political background, further steps, message to new players	Daniel Fraile
15 min.	PV Cycle: the technical view	Raymund Schäffler
	Other short notes and discussion	all
Topic 3 ~10.30-12.30h	**Standardization:** EPIA together with SEMI is trying to support and install standardization in PV manufacturing; can that support thin film PV? How could the roadmap on standardization be?	
10 min.	Standardization: what have been already and what should be done from the sight of EPIA	Daniel Fraile
45 min.	"How can a new and emerging technology as Thin Film PV profit from Standardization?"	Prof. W. Bergholz, Univ. Bremen
	Other short notes and discussion	all
Topic 4 ~14.00-16.00h	EC Integrated Project **PERFORMANCE** Presentation of the project and already done results of work, further plans; lifetime and module certification; offer to all thin film manufactures to participate	
	Project Structure	Daniel Fraile
	Results, actual status and further work to be done of the subprojects	Ewan Dunlop
	Other short notes and discussion	all
16 h	End of workshop	

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Status and Perspectives of Thin Film Solar Cell Production

Arnulf Jäger-Waldau

European Commission, DG JRC, Ispra
Institute for Environment and Sustainability
Renewable Energies

Renewable Energies

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Disclaimer

- The capacity numbers were collected from Press Announcements of the different companies with a cut-off date End of October 2007.
- There is a sometimes quite high uncertainty in the overall figure as well as the time lines. As I pointed out in the presentation I consider 50% to be realistic in the given time frame.
- On slide 10 and 11 the 4.5 and 2€/Wp are possible system prices – not project costs - for the customer. Therefore, possible costs for the acquisition or lease of land is not included.
  - The actual BOS/installation costs might vary from project to project. Therefore, I added the case of a 50% BOS and a 100% BOS penalty in the case of 6% modules.
  - The figures for the modules represent the possible selling price of the module.
- The use of the material is permitted as long as the sources are acknowledged.
- Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use, which might be made of the following information.

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- Photovoltaics Overview
- Industry
- Cost Reduction and Learning Curves
- Markets
- Conclusions

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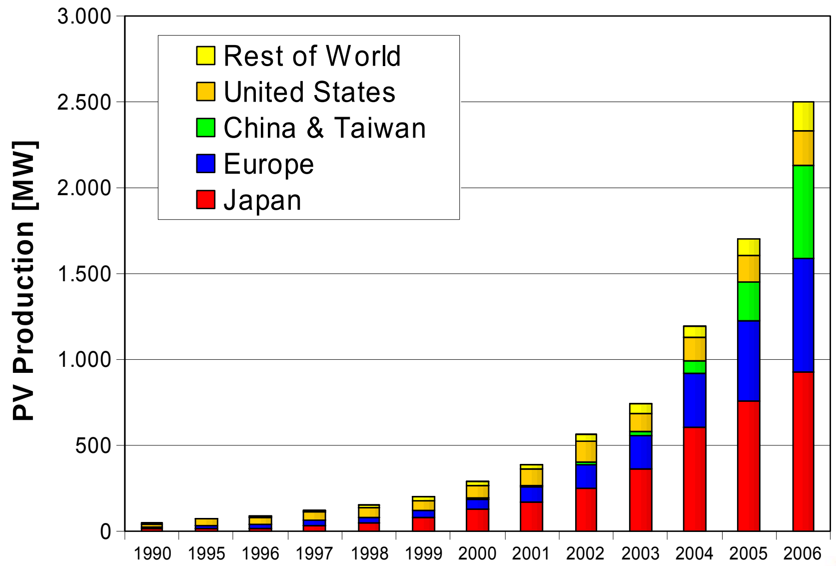
World-wide PV Cell/Module Production



Data source: PV News

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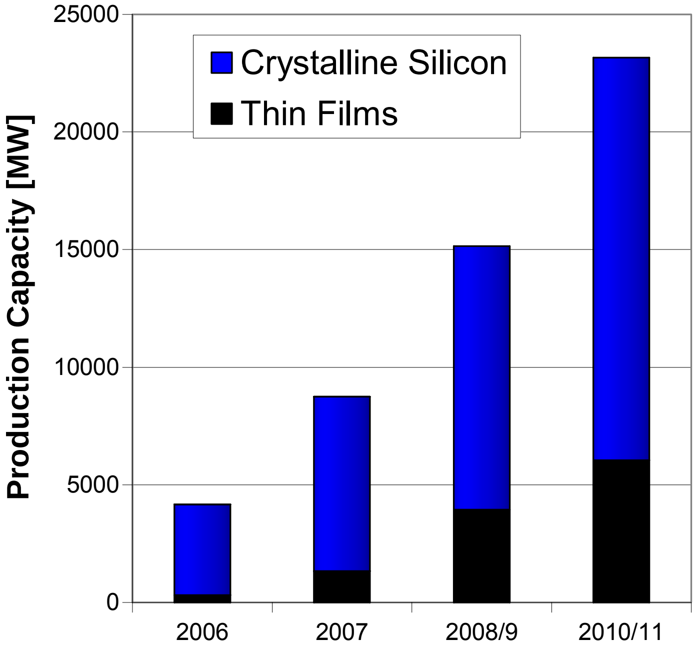
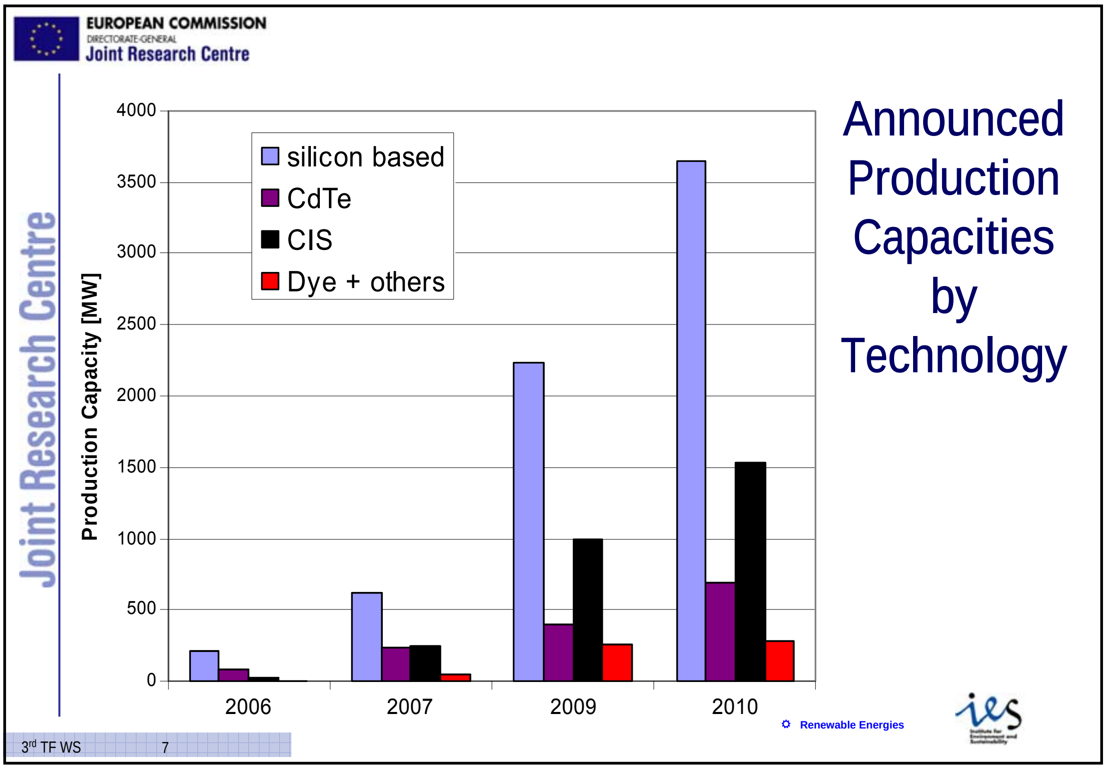
Announced Capacity Increases



Thin Film Industry

- more than 130 companies world wide (range : research to production)
- 21 companies have produced thin film PV in 2006
- 82 companies have announced plans to increase their production capacities
- 32 in Europe, 14 China, 19 USA, 9 Japan, 8 ROW
- 50 silicon based
- 19 Cu(In,Ga)2(Se,S)2
- 8 CdTe
- 5 Dye & others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Announced Production Capacities by Technology
Production Capacity [MW]
4000
3500
3000
2500
2000
1500
1000
500
0
silicon based
CdTe
CIS
Dye + others
2006
2007
2009
2010
Renewable Energies
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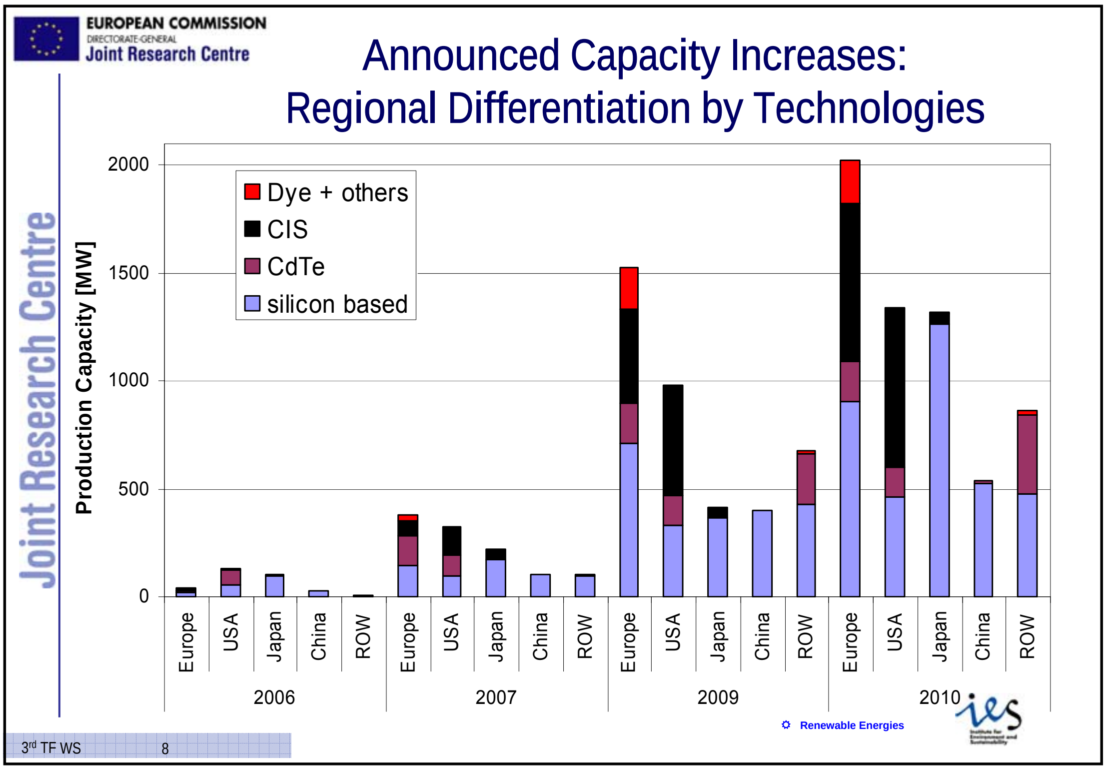
EUROPEAN COMMISSION
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Joint Research Centre
Announced Capacity Increases:
Regional Differentiation by Technologies
Production Capacity [MW]
2000
1500
1000
500
0
Dye + others
CIS
CdTe
silicon based
Europe
USA
Japan
China
ROW
2006
2007
2009
2010
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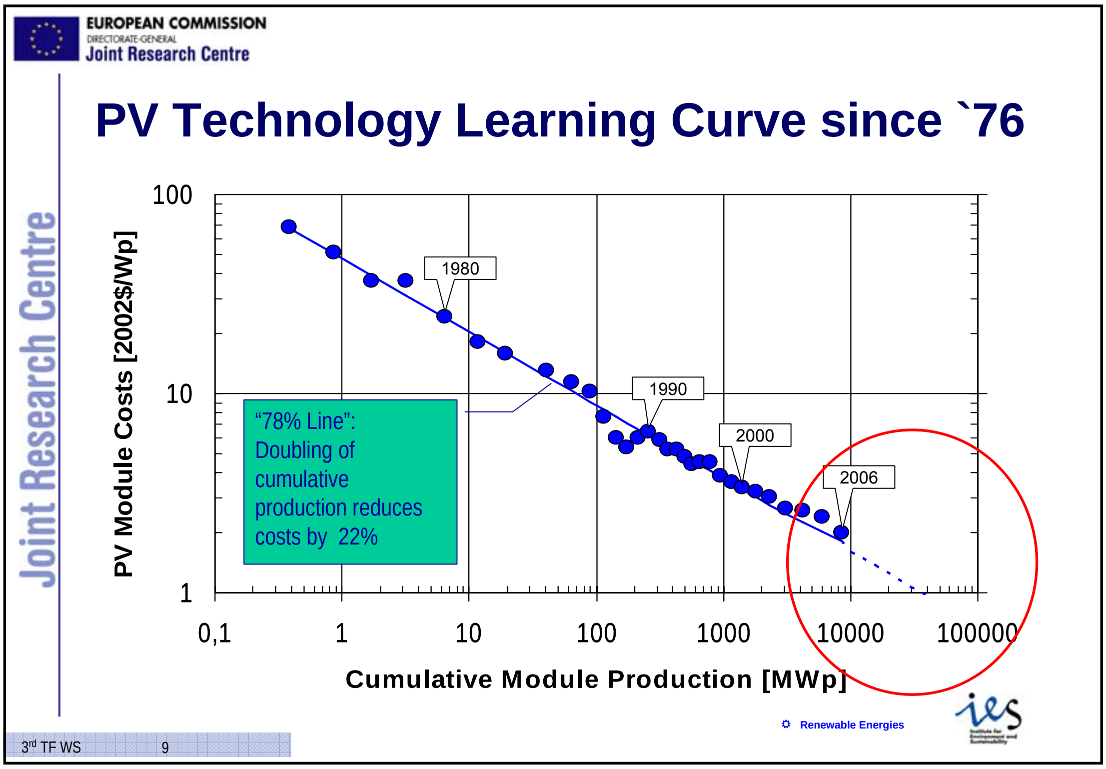
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PV Technology Learning Curve since `76
PV Module Costs [2002$/Wp]
100
10
1
0,1
1
10
100
1000
10000
100000
Cumulative Module Production [MWp]
1980
1990
2000
2006
"78% Line":
Doubling of
cumulative
production reduces
costs by 22%
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Renewable Energies
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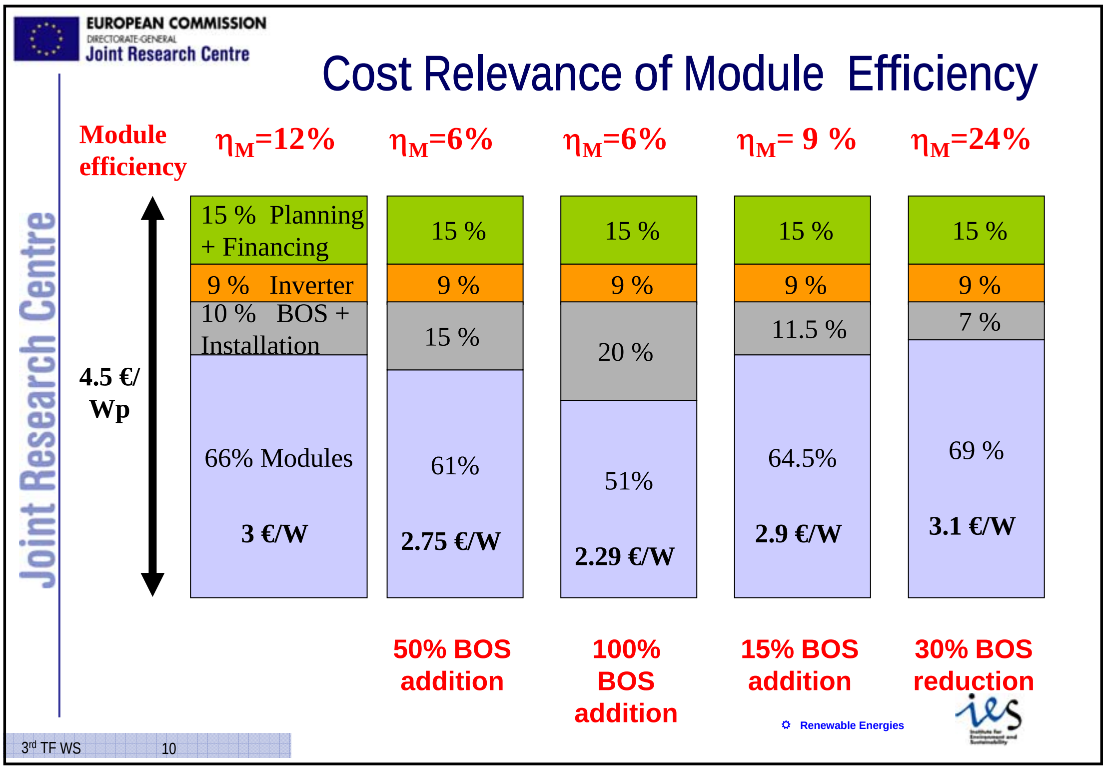
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Cost Relevance of Module Efficiency
Module efficiency
ηM=12%
ηM=6%
ηM=6%
ηM= 9 %
ηM=24%
4.5 €/Wp
15 % Planning + Financing
9 % Inverter
10 % BOS + Installation
66% Modules
3 €/W
15 %
9 %
15 %
61%
2.75 €/W
15 %
9 %
20 %
51%
2.29 €/W
15 %
9 %
11.5 %
64.5%
2.9 €/W
15 %
9 %
7 %
69 %
3.1 €/W
50% BOS addition
100% BOS addition
15% BOS addition
30% BOS reduction
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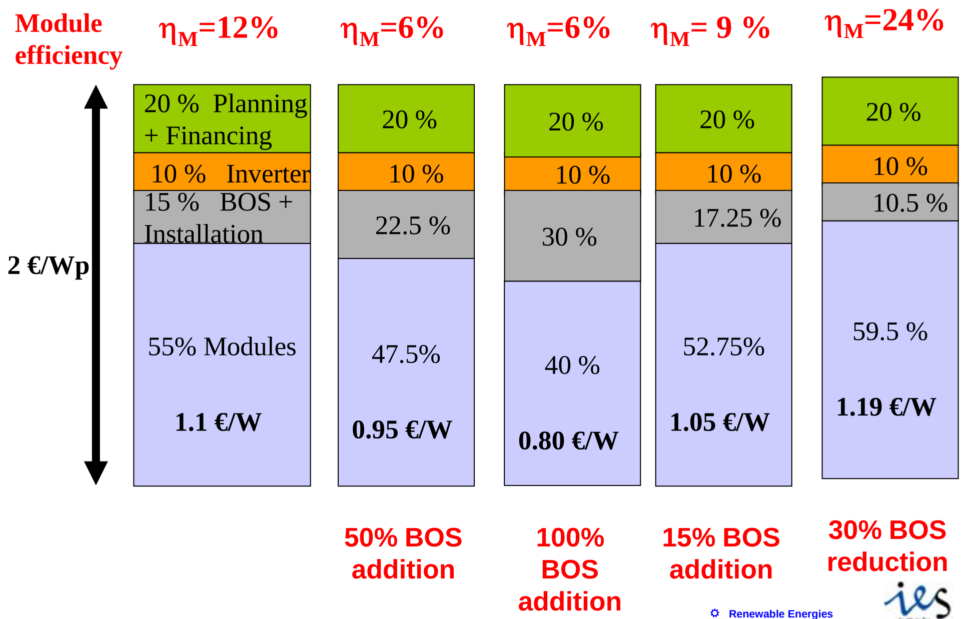
Cost Relevance of Module Efficiency



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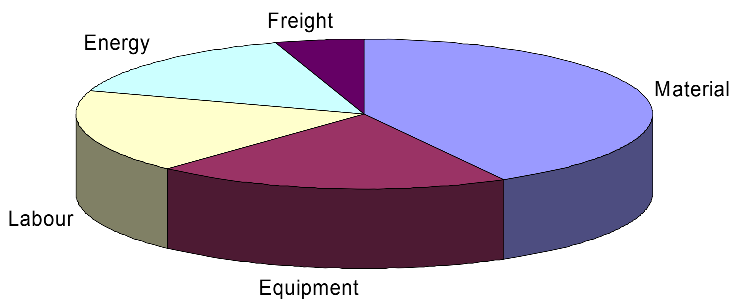
Average Thin Film Cost Structure



Technology dependent Drivers

Deposition Process: Dominates Energy
Deposition Materials: Dominates Depreciation
Package/Assembly: Dominates Materials

Common Drivers

Material Cost: Volume, Efficiency
Depreciation: Throughput, Efficiency
Labour: Throughput, Automation, Efficiency
Energy: Throughput, Efficiency

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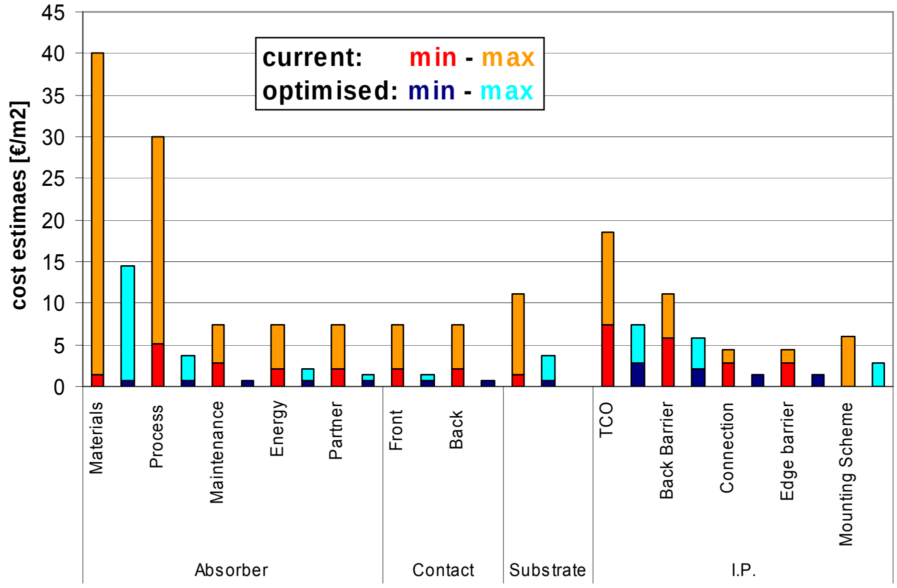
Thin Film Cost Reduction Potentials



3rd TF WS 13

Data: K. Zweibel

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Thin Film Cost Reduction Potentials

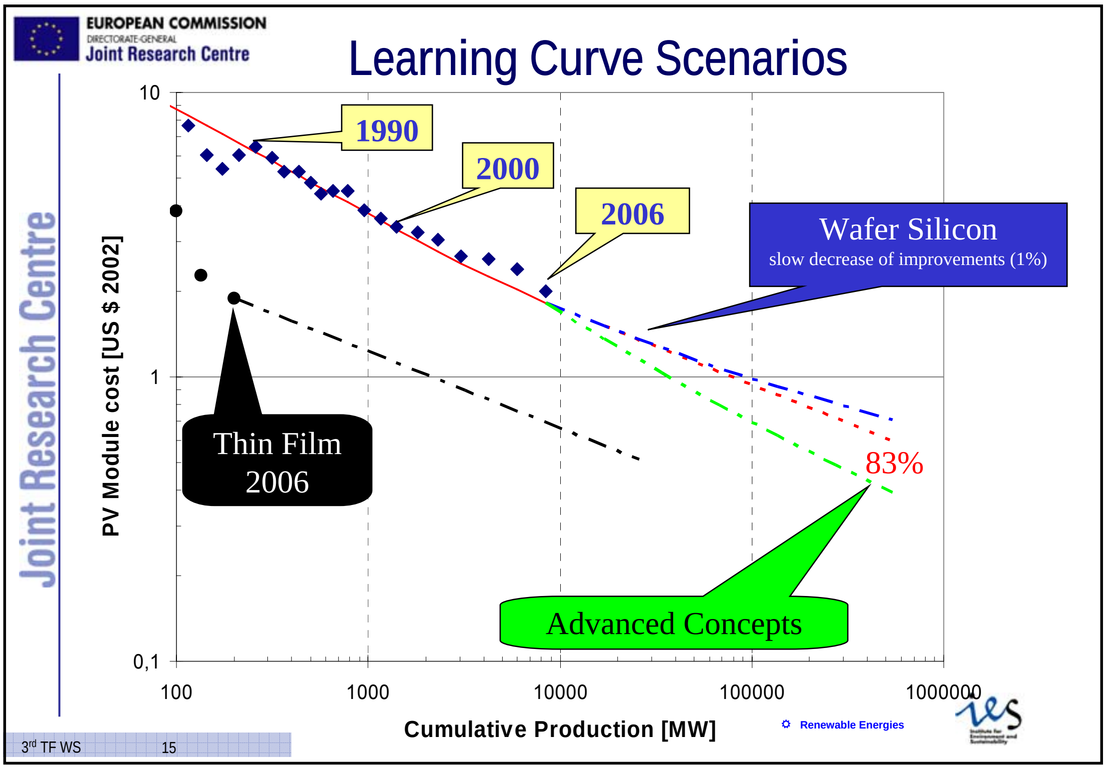
Current:
Active Layers: 20 – 98 €/m^2
Inactive Parts: 19 – 26 €/m^2
Total: 39 – 124 €/m^2

Optimised:
Active Layers: 5.5 – 23 €/m^2
Inactive Parts: 8 – 11 €/m^2
Total: 13.5 – 34 €/m^2

Renewable Energies

3rd TF WS 14

Data: K. Zweibel


EUROPEAN COMMISSION
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Learning Curve Scenarios
PV Module cost [US $ 2002]
10
1
0,1
100
1000
10000
100000
1000000
Cumulative Production [MW]
1990
2000
2006
Wafer Silicon
slow decrease of improvements (1%)
Thin Film
2006
83%
Advanced Concepts
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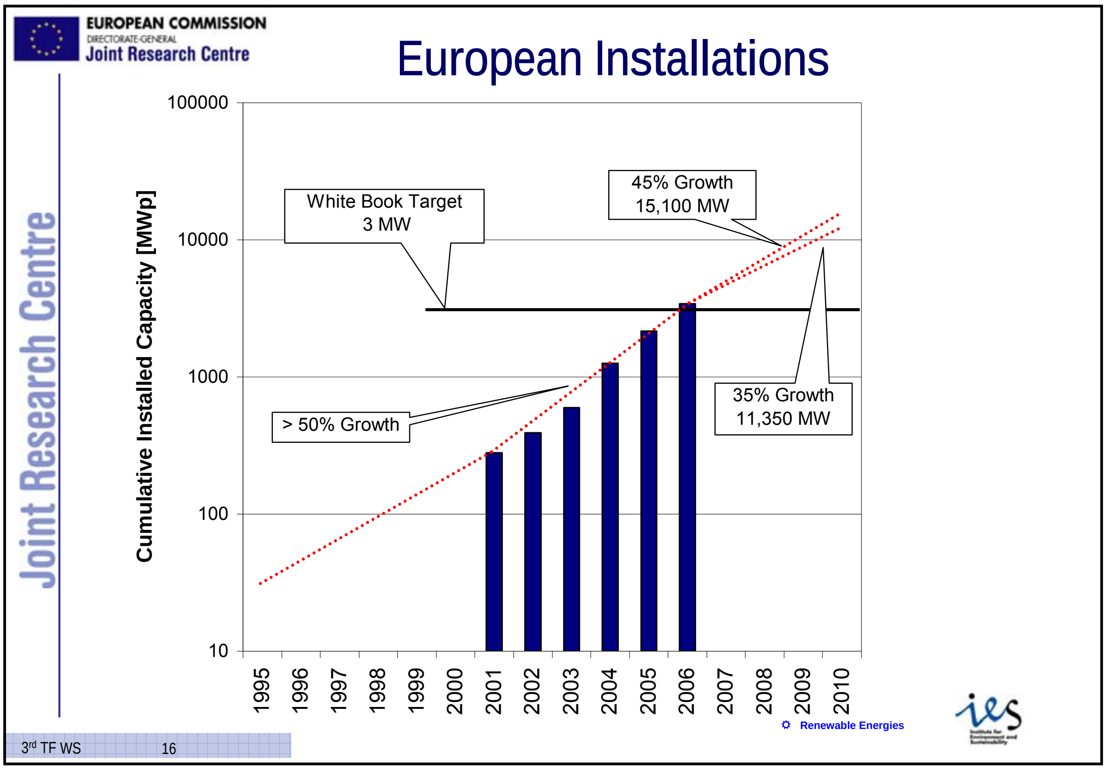
Renewable Energies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European Installations
Cumulative Installed Capacity [MWp]
100000
10000
1000
100
10
White Book Target
3 MW
45% Growth
15,100 MW
> 50% Growth
35% Growth
11,350 MW
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
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Market Estimates

PV News	Europe + Japan + USA 35% Growth	Europe + Japan + USA 45% Growth
2006: 2,500 MW	1,680 MW	1,680 MW
2010: 7,140 MW	5,200 MW	7,700 MW
2011: 9,300 MW	7,000 MW	11,165 MW

Renewable Energies

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Conclusions

☺ Thin Film PV Production Capacities grow faster than the already high PV growth rates

☹ High uncertainty about time schedule of about 50% of the announced capacity increases

☺ If production volume is ramped up according to plans, Thin Film PV has the potential to reach the 1 €/Wp cost target at the end of this decade

😐 Markets for the next decade will still depend on public support

Renewable Energies

3rd TF WS 18


Thank you for your attention!
Photo by Steve Locke

Aspekte der Kostenreduktion bei der großflächigen Herstellung a-Si basierter Dünnschichtmodule

Ch. Daube
Director Global Product Management Solar

think it. apply it.

Contents

Safe Harbor Statement

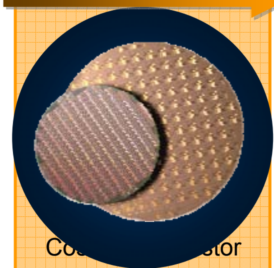
This presentation contains forward-looking statements, including those relating to Applied's product capabilities, technology leadership, strategy to reduce solar production costs, growth opportunities, served available market; customers' plans; and the solar industry outlook. These statements are subject to known and unknown risks and uncertainties that could cause actual results to differ materially from those expressed or implied by such statements, including without limitation: (a) broadening of demand in the solar industry, which is subject to many factors, including global economic conditions, the cost-effectiveness and performance of photovoltaic (PV) products compared to conventional and other alternative energy sources, technological innovations, availability and cost of raw materials such as silicon, evolving industry standards, changing customer and end-user requirements, government subsidies and economic incentives for alternative energy development, and geopolitical uncertainties; (b) customers' capacity requirements and timing, rate and amount of capital spending for new technology; (c) Applied's ability to: (i) accurately predict the characteristics of, and capitalize on opportunities in, the emerging PV market, (ii) successfully adapt its existing products and develop and commercialize new products that enable increased solar cell efficiency and performance at a lower cost, (iii) recruit, incent and retain key employees, (iv) obtain and protect intellectual property rights in key technologies, (iv) develop, deliver and support a broad range of products, and (v) integrate acquired businesses; and (d) other risks described in Applied's SEC filings. All forward-looking statements are based on management's estimates, projections and assumptions as of February 27, 2007, and Applied undertakes no obligation to update any such statements.

Applied Materials' Overview

- Revenue (Last 4 Quarters)
  - Approx. $9.1 Billion
- Worldwide Employees
  - Approx. 14,000
- Worldwide Locations
  - 14 countries
  - Approx. 75 sales / service locations
  - Manufacturing in North America, Germany, Israel, Taiwan, U.K.
  - Development in North America, Asia, Europe and Israel
- RD&E Investment (FY'01 – FY'05)
  - $1 Billion/Year
- Service
  - 3,300 field engineers
- Installed Base
  - >19,000 Silicon IC systems
  - >500 Flat Panel Display systems
  - >500 Glass and Web Coating Systems

Applied Materials Enables Industry Growth by Driving Cost Reduction….

FIRST



1974	2004
4 trillion	1,400,000 trillion
10 cents	5 nano-dollars

20,000,000x Cost Reduction

Source: SIA, IC Knowledge LLC

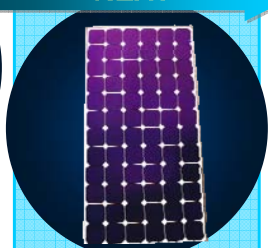
THEN

1995	2005
0.3 million m^2	25 million m^2
$30,000 / m^2	$1,500 / m^2

20x Cost Reduction

Source: Display Search, Nikkei BP, Applied Materials

NEXT



Cost per watt

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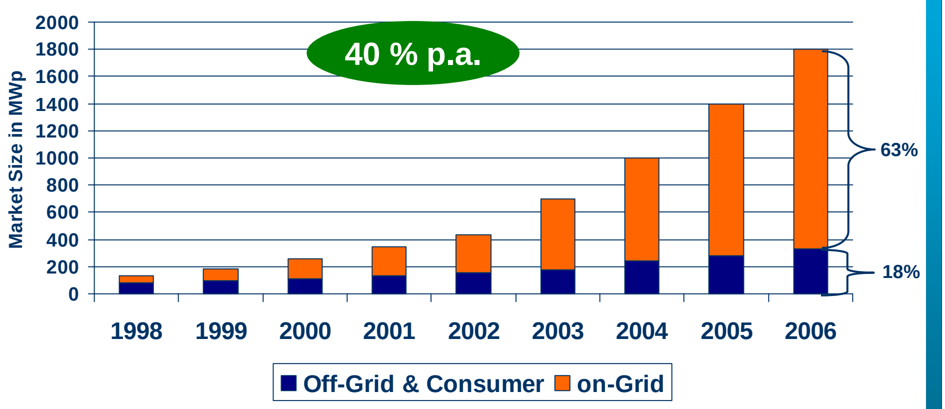
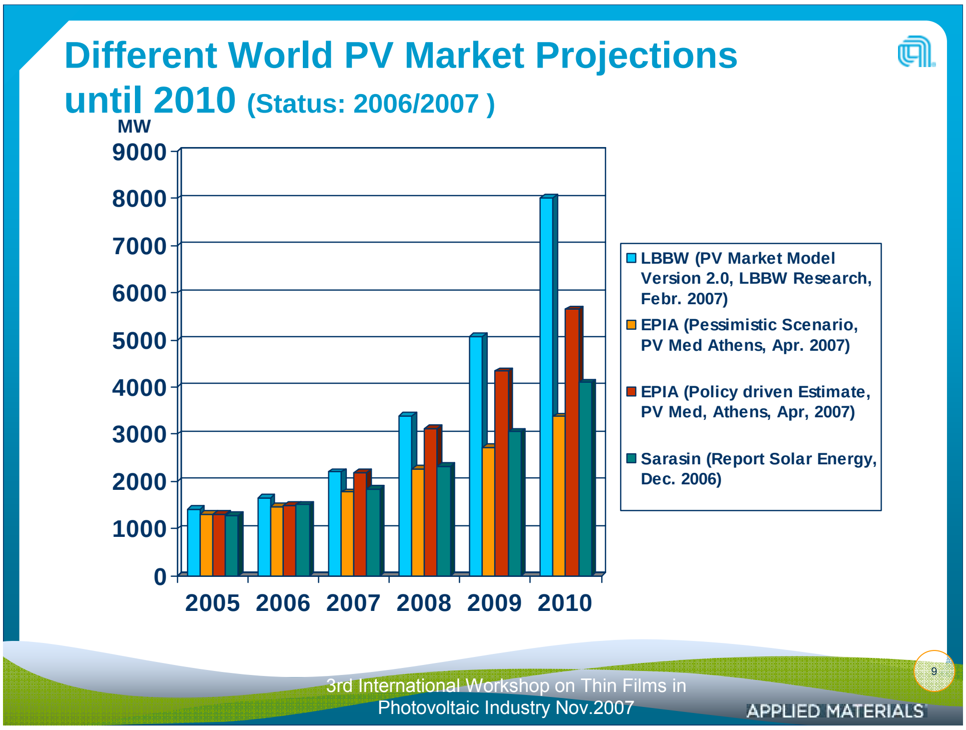
- **SCALE OF MANUFACTURING**
  - **Market growth**
- PRODUCT COST REDUCTION
  - Cost per m^2
    - Glass/display
      - Size
      - Process
  - Watts per m^2
    - Materials science
    - Yield & control
    - IC know-how & leverage
- THIN FILM LINE CONCEPT
  - Configuration
  - Products
- Summary

World PV Market Size and Application Segmentation





Different World PV Market Projections
until 2010 (Status: 2006/2007)
MW
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2005 2006 2007 2008 2009 2010
LBBW (PV Market Model Version 2.0, LBBW Research, Febr. 2007)
EPIA (Pessimistic Scenario, PV Med Athens, Apr. 2007)
EPIA (Policy driven Estimate, PV Med, Athens, Apr, 2007)
Sarasin (Report Solar Energy, Dec. 2006)
3rd International Workshop on Thin Films in Photovoltaic Industry Nov.2007
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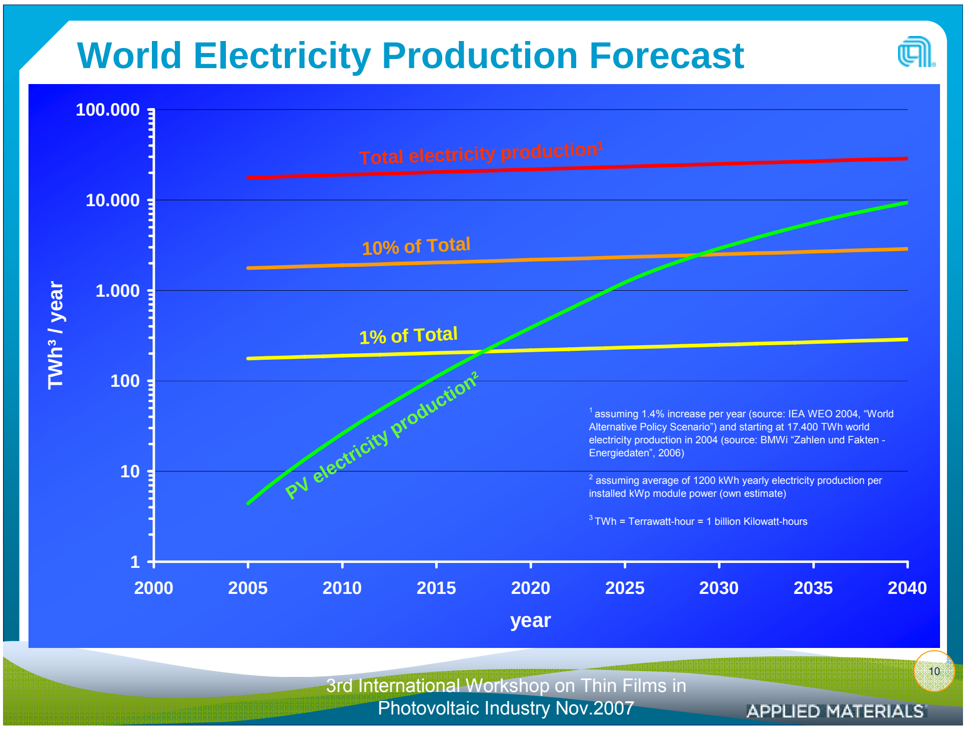

World Electricity Production Forecast
100.000
10.000
1.000
100
10
1
TWh³ / year
Total electricity production¹
10% of Total
1% of Total
PV electricity production²
¹ assuming 1.4% increase per year (source: IEA WEO 2004, "World Alternative Policy Scenario") and starting at 17.400 TWh world electricity production in 2004 (source: BMWi "Zahlen und Fakten - Energiedaten", 2006)
² assuming average of 1200 kWh yearly electricity production per installed kWp module power (own estimate)
³ TWh = Terrawatt-hour = 1 billion Kilowatt-hours
2000 2005 2010 2015 2020 2025 2030 2035 2040
year
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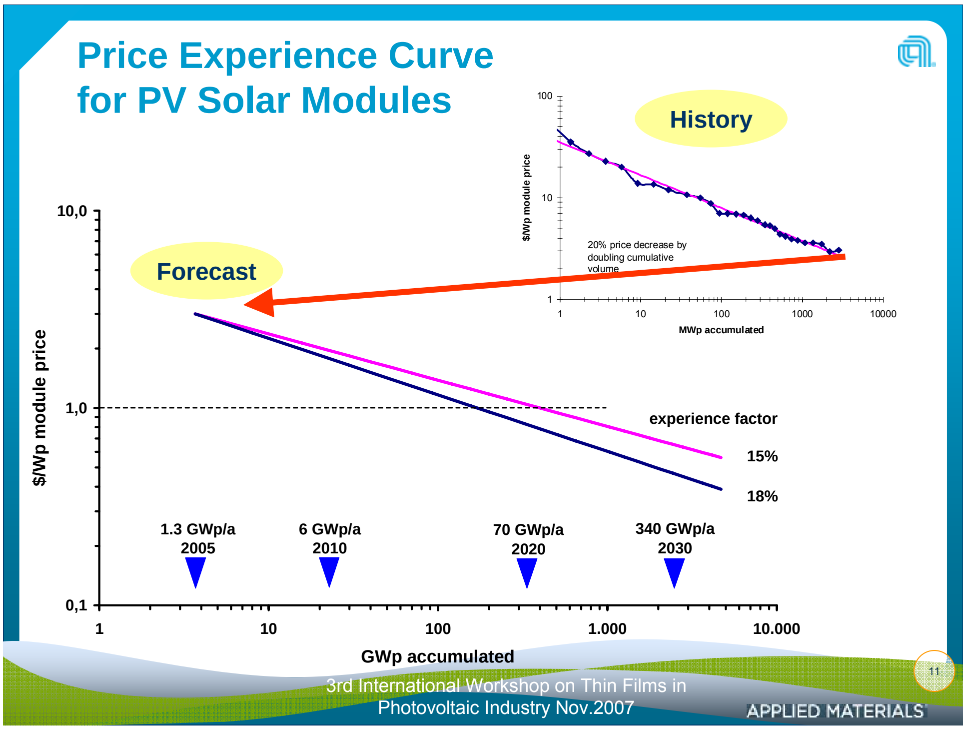
Price Experience Curve
for PV Solar Modules
History
$/Wp module price
MWp accumulated
20% price decrease by doubling cumulative volume
Forecast
10,0
1,0
0,1
$/Wp module price
experience factor
15%
18%
1.3 GWp/a
2005
6 GWp/a
2010
70 GWp/a
2020
340 GWp/a
2030
1
10
100
1.000
10.000
GWp accumulated
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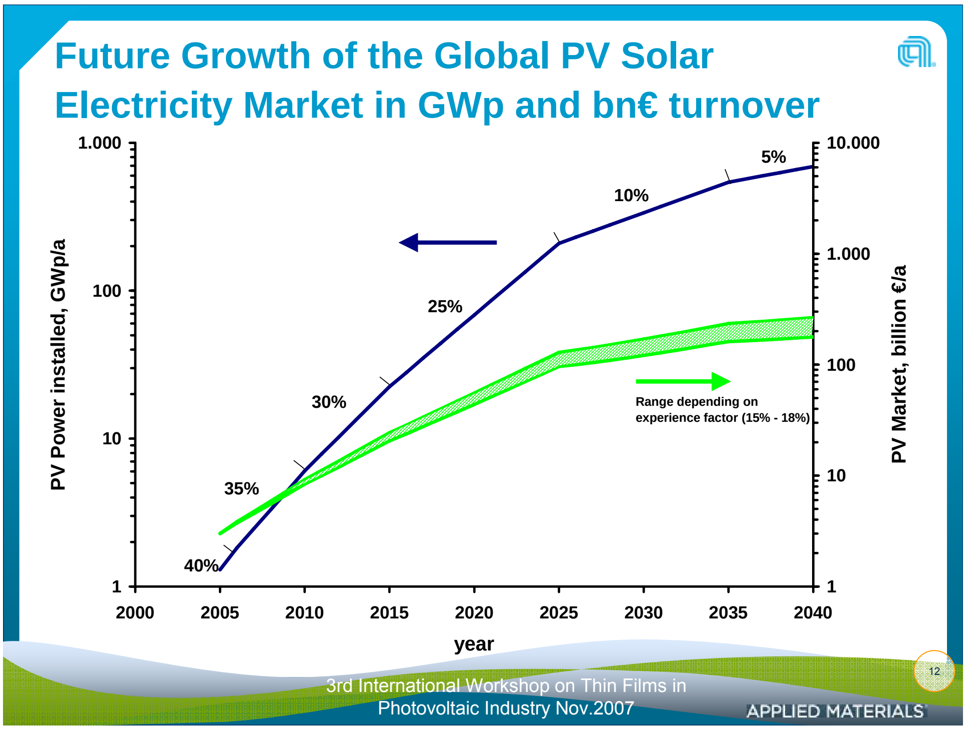
Future Growth of the Global PV Solar
Electricity Market in GWp and bn€ turnover
1.000
100
10
1
PV Power installed, GWp/a
10.000
1.000
100
10
1
PV Market, billion €/a
40%
35%
30%
25%
10%
5%
Range depending on
experience factor (15% - 18%)
2000
2005
2010
2015
2020
2025
2030
2035
2040
year
3rd International Workshop on Thin Films in
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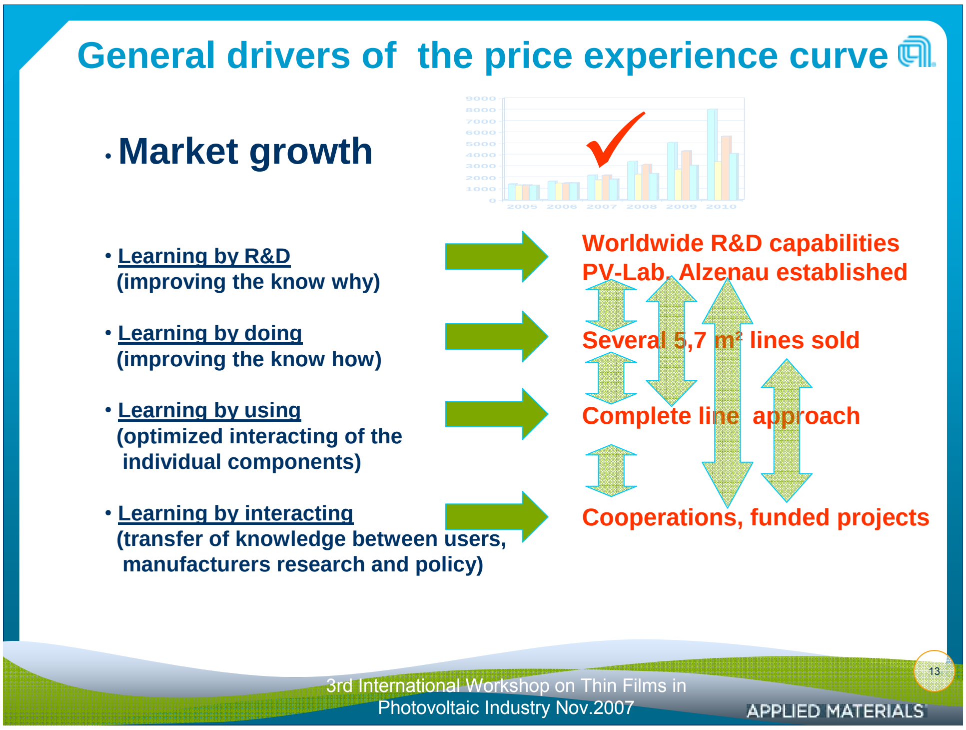
General drivers of the price experience curve
• Market growth
• Learning by R&D
(improving the know why)
• Learning by doing
(improving the know how)
• Learning by using
(optimized interacting of the individual components)
• Learning by interacting
(transfer of knowledge between users, manufacturers research and policy)
Worldwide R&D capabilities
PV-Lab. Alzenau established
Several 5,7 m² lines sold
Complete line approach
Cooperations, funded projects
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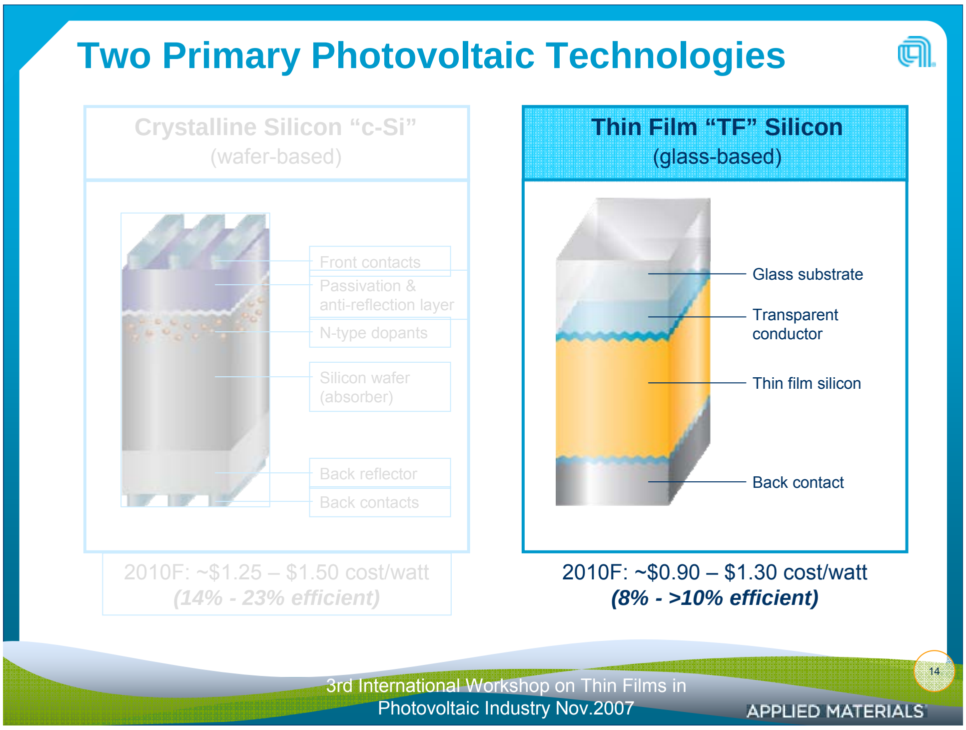
Two Primary Photovoltaic Technologies
Crystalline Silicon "c-Si"
(wafer-based)
Front contacts
Passivation & anti-reflection layer
N-type dopants
Silicon wafer (absorber)
Back reflector
Back contacts
2010F: ~$1.25 – $1.50 cost/watt
(14% - 23% efficient)
Thin Film "TF" Silicon
(glass-based)
Glass substrate
Transparent conductor
Thin film silicon
Back contact
2010F: ~$0.90 – $1.30 cost/watt
(8% - >10% efficient)
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a-Si based Thin Film Technologies have…

a) **low cost (price) per m²** (BIPV) at lower eta (4-6%)
- deposition area: 0,6 → 1,4 → 3 → 5 → 10 m²
- utilize technology development in TFT technology (e.g. ASI)
- creation of semi transparency

b) **low cost (price) per Wp**
- a-Si/µc-Si
- efficiency 8% today, up to 10 % in 2010 and 14 % in 2030

c) **no polysilicon supply constraint**

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APPLIED MATERIALS

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- SCALE OF MANUFACTURING
  - Market growth
- **PRODUCT COST REDUCTION**
  - **Cost per m²**
    - **Glass/display**
      - **Size**
      - **Process**
  - **Watts per m²**
    - **Materials science**
    - **Yield & control**
    - **IC know-how & leverage**
- THIN FILM LINE CONCEPT
  - Configuration
  - Products
- Summary

$$\$\ \text{Production / Watt} = \frac{\text{Cost / m}^2}{\text{Watt / m}^2}$$

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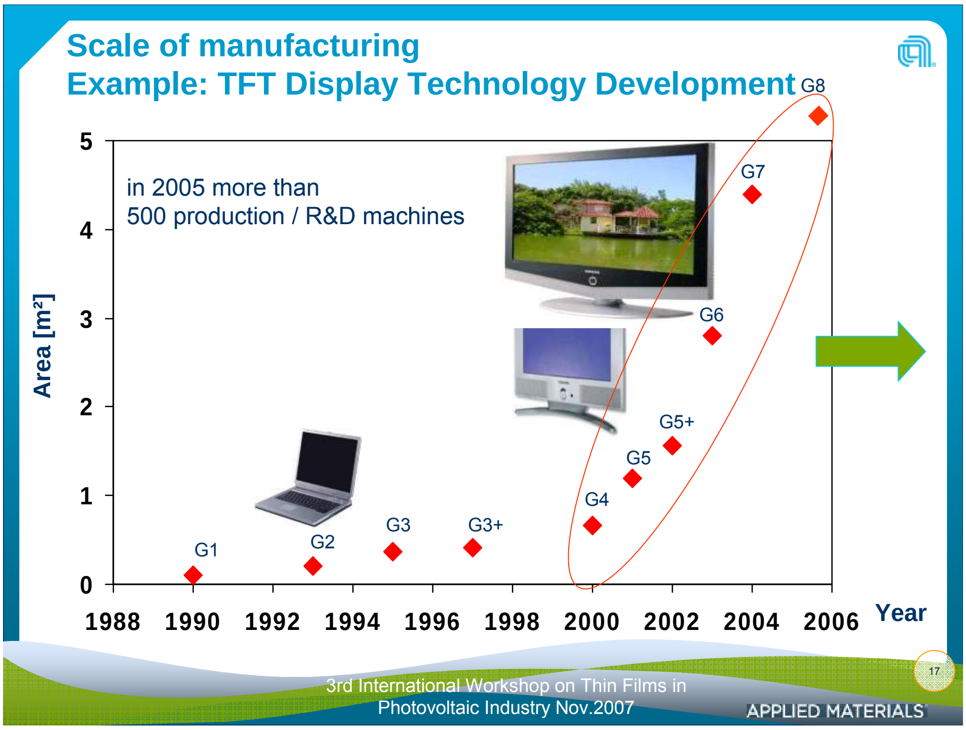
APPLIED MATERIALS


Scale of manufacturing
Example: TFT Display Technology Development
in 2005 more than
500 production / R&D machines
Area [m²]
0
1
2
3
4
5
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
G1
G2
G3
G3+
G4
G5
G5+
G6
G7
G8
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APPLIED MATERIALS
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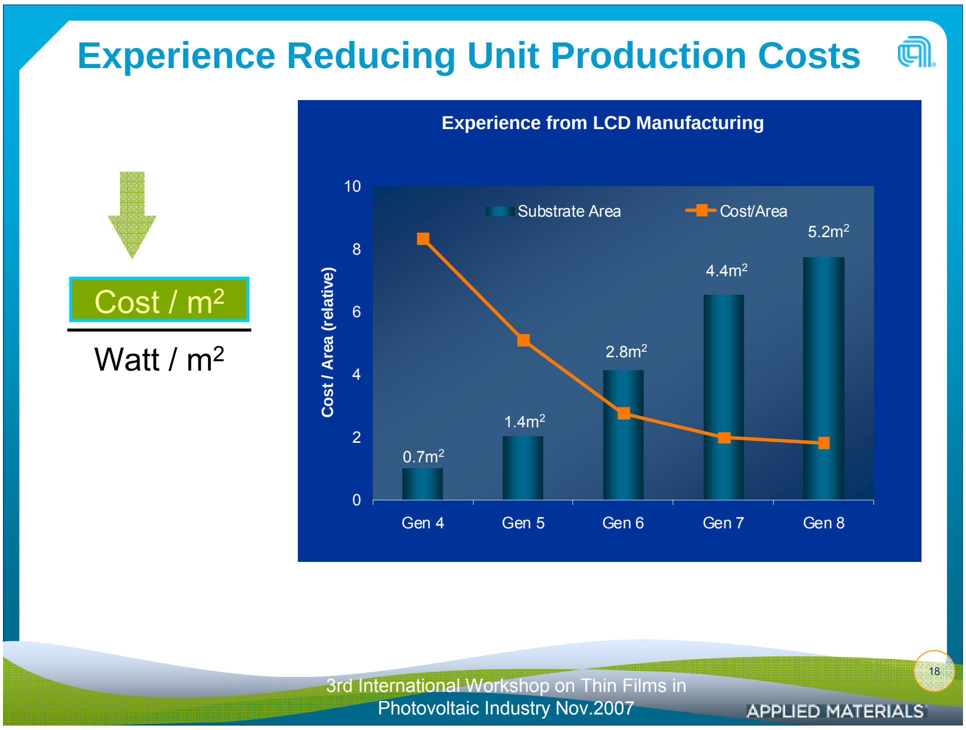
Experience Reducing Unit Production Costs
Cost / m²
Watt / m²
Experience from LCD Manufacturing
Substrate Area
Cost/Area
Cost / Area (relative)
0
2
4
6
8
10
0.7m²
1.4m²
2.8m²
4.4m²
5.2m²
Gen 4
Gen 5
Gen 6
Gen 7
Gen 8
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APPLIED MATERIALS
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Applied's Capabilities
Large Area Platforms
ATON™
AKT50K PECVD
MULTIWEB™
Automation
Process Technology
• Yield & control
• IC know-how & leverage
Integration
Service & Support
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APPLIED MATERIALS
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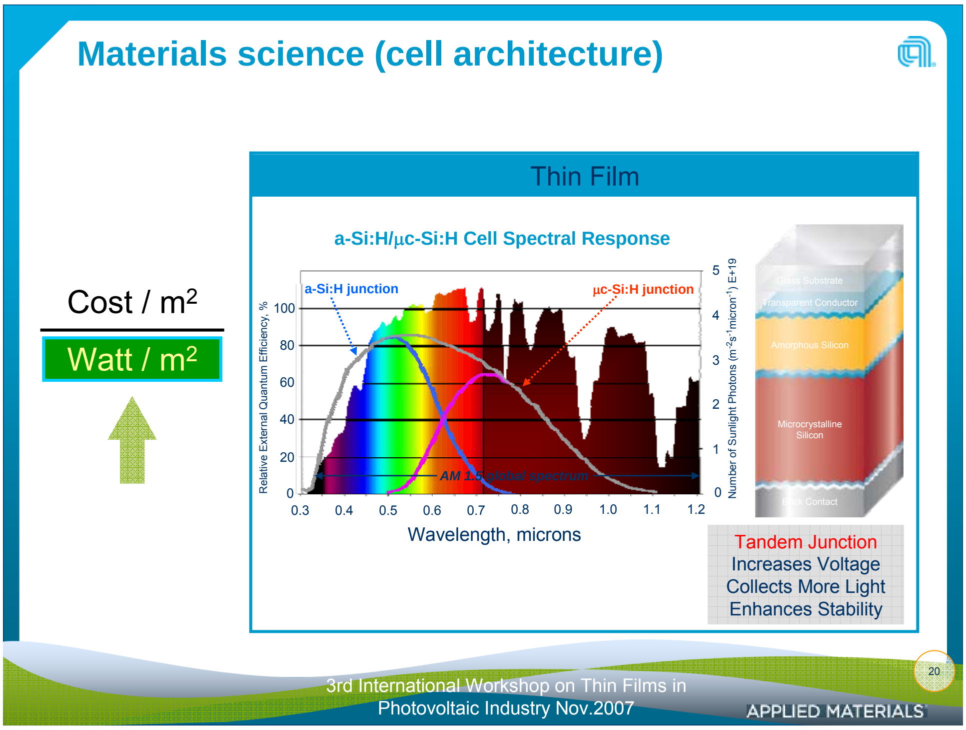

Materials science (cell architecture)
Cost / m²
Watt / m²
Thin Film
a-Si:H/µc-Si:H Cell Spectral Response
a-Si:H junction
µc-Si:H junction
Relative External Quantum Efficiency, %
Number of Sunlight Photons (m⁻²s⁻¹micron⁻¹) E+19
AM 1.5 global spectrum
Wavelength, microns
Glass Substrate
Transparent Conductor
Amorphous Silicon
Microcrystalline Silicon
Back Contact
Tandem Junction
Increases Voltage
Collects More Light
Enhances Stability
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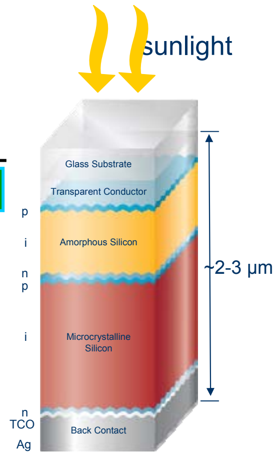
a-Si:H/µc-Si:H Tandem Cells

Cost / m²

Watt / m²



a-Si:H/µc-Si:H general advantages
- silicon technology
- real thin-film concept
- ideal combination of materials for tandem cells
- high efficiencies demonstrated

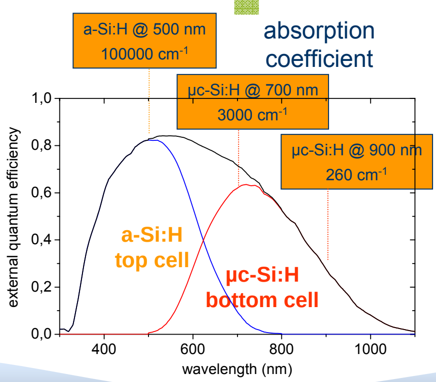
µc-Si:H compared to a-Si:H
- improved red/NIR-response
- high stability

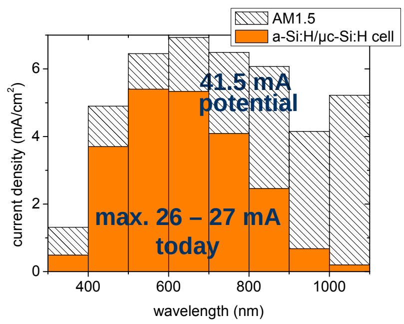
potential
- TCO/light trapping
- high deposition rates necessary
- large area deposition

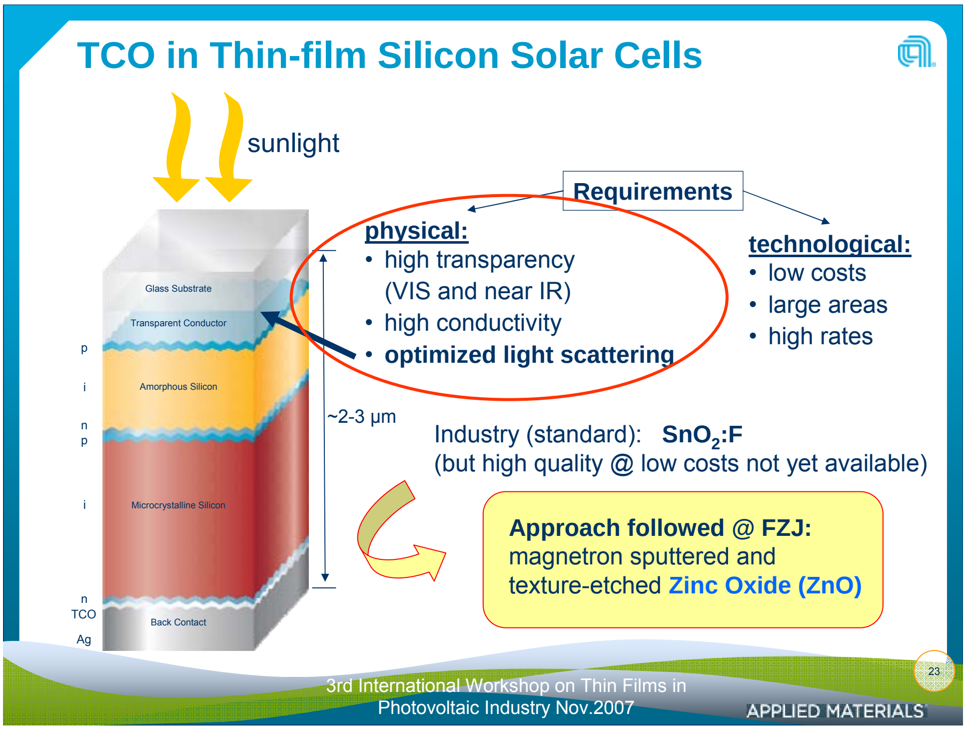
Material science: Light-trapping

Cost / m²

Watt / m²






TCO in Thin-film Silicon Solar Cells
sunlight
Glass Substrate
Transparent Conductor
Amorphous Silicon
Microcrystalline Silicon
Back Contact
p
i
n
p
i
n
TCO
Ag
~2-3 µm
Requirements
physical:
• high transparency (VIS and near IR)
• high conductivity
• optimized light scattering
technological:
• low costs
• large areas
• high rates
Industry (standard): SnO_2:F
(but high quality @ low costs not yet available)
Approach followed @ FZJ:
magnetron sputtered and texture-etched Zinc Oxide (ZnO)
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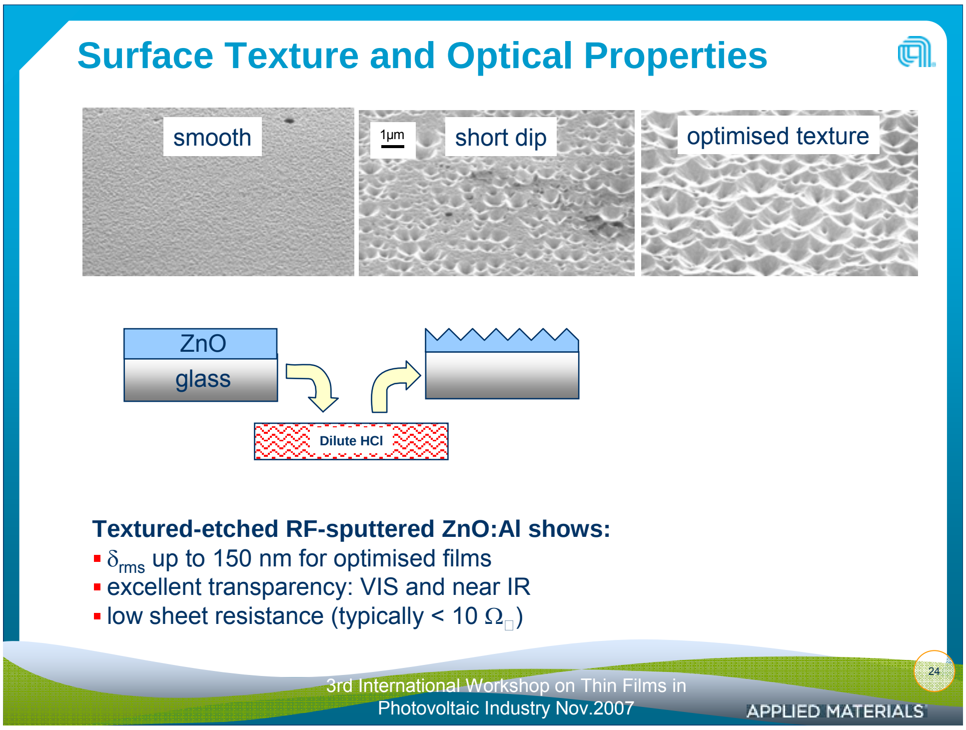
APPLIED MATERIALS


Surface Texture and Optical Properties
smooth
1µm
short dip
optimised texture
ZnO
glass
Dilute HCl
Textured-etched RF-sputtered ZnO:Al shows:
▪ δ_{rms} up to 150 nm for optimised films
▪ excellent transparency: VIS and near IR
▪ low sheet resistance (typically < 10 $\Omega_{\square}$)
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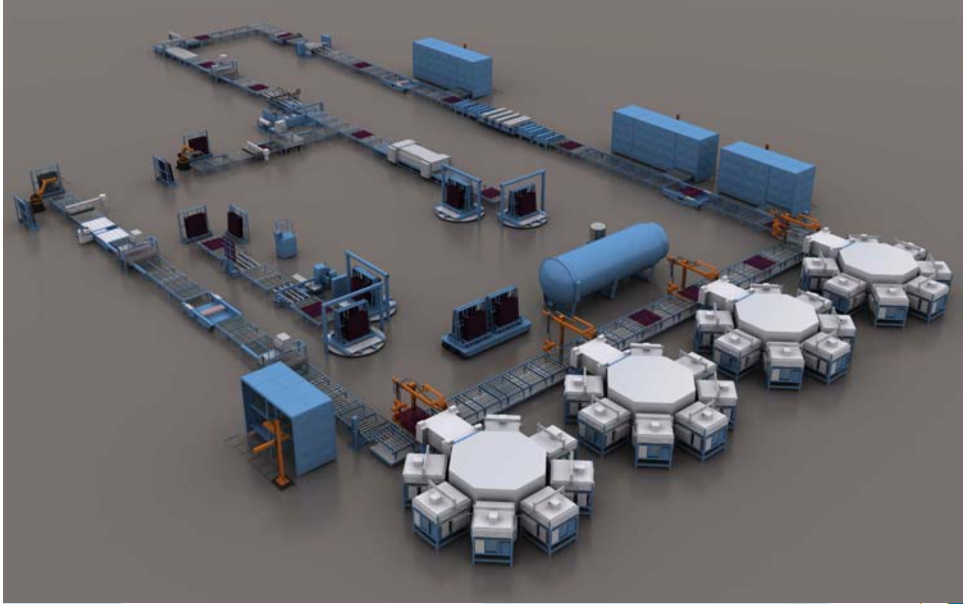
APPLIED MATERIALS

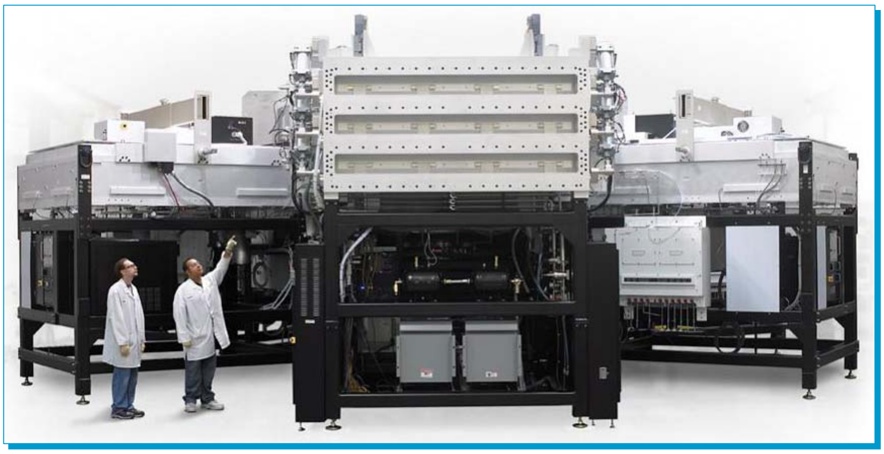
Contents

- INTRODUCTION APPLIED MATERIALS
- SCALE OF MANUFACTURING
  - Market growth
- PRODUCT COST REDUCTION
  - Cost per m^2
    - Glass/display
      - Size
      - Process
  - Watts per m^2
    - Materials science
    - Yield & control
    - IC know-how & leverage
- **THIN FILM LINE CONCEPT**
  - **Configuration**
  - **Products**
- Summary

Introducing SunFab™ Thin Film Line



SunFab PECVD 5.7 System for Thin Film Si



Processes glass at 4 times the size of Applied Materials' nearest competitor

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APPLIED MATERIALS

Scale-Up of Deposition to 5.7m^2 Glass Size

Demonstration of first 5.7 m^2 deposited a-Si material for solar. Visually shows the size of the substrate and engineer

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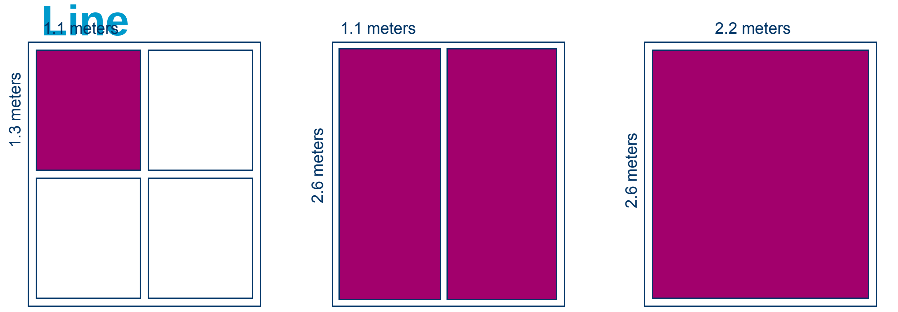
APPLIED MATERIALS

Module Sizes available from the SunFab Line



Best for Roof Top
- Standard size for easy handling
- Tandem junction best to save area
- Weight is ~25kg

Best for Solar Farm
- Large module size to save BOS costs
- Single junction already gives high power
- Weight is ~50kg
- Convenient near drop in solution for BOS

Best for BIPV + Solar Utilities
- Single piece of see-through window gives maximum use of area & saves lamination costs
- See-through results in less conv efficiency
- Weight is ~100kg

Modules can be ¼ size, ½ size or full size to address various market segments

Fact Sheet SunFab™

- Up to 75MW per production line
- ¼ size, ½ size and full size modules
- 6% for single junction (>340 Wp on full size)
- 8% with path to 10% for tandem junction (>450 Wp → 570 Wp)
- Glass-PVB-glass is lowest cost / highest reliability; mass production approach adapted from automobile and architectural glass markets
- Dimensions SunFab™ – 80m x 140m
- Employees – Approximately 130, including operations, engineering and management

Contents

Summary SunFab™

- **Go Large**
  - Enables 5.7 m^2 – 4x larger than today's largest thin film modules
  - Reduce production costs (labor, j-box, capital, overhead)
  - Reduce installation costs (labor, cabling, mounting)
  - Technology / toolset to enable GW-scale production
  - The transition is well underway
- **Proven**
  - Based on large-area PECVD tool with nearly 600 installed systems
  - PVD for back contact from leading glass coating platform: >190 systems
- **Mass production**
  - All other tools sourced from established leaders in their respective platforms / technologies
  - All elements necessary to produce a world class product – integrated production line from glass in to panel out; process integration; factory automation software and global service and support relationship


Thank you for your attention
APPLIED MATERIALS

oerlikon
solar

Agenda

- Oerlikon Overview
- Oerlikon Solar as Technology and Market Leader
- PV-Solar Driver: Cost Reduction

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oerlikon

Six areas of high tech competencies

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Oerlikon Solar	Oerlikon Coating	Oerlikon Vacuum	Oerlikon Textile	Oerlikon Drive Systems	Oerlikon Components

oerlikon solar ▪ Thin Film ▪ Laser ▪ Mechatromics	oerlikon balzers oerlikon systems	oerlikon leybold vacuum	oerlikon barmag oerlikon neumag oerlikon saurer oerlikon schlafhorst oerlikon textile components	oerlikon graziano oerlikon fairfield	oerlikon esec oerlikon optics oerlikon space

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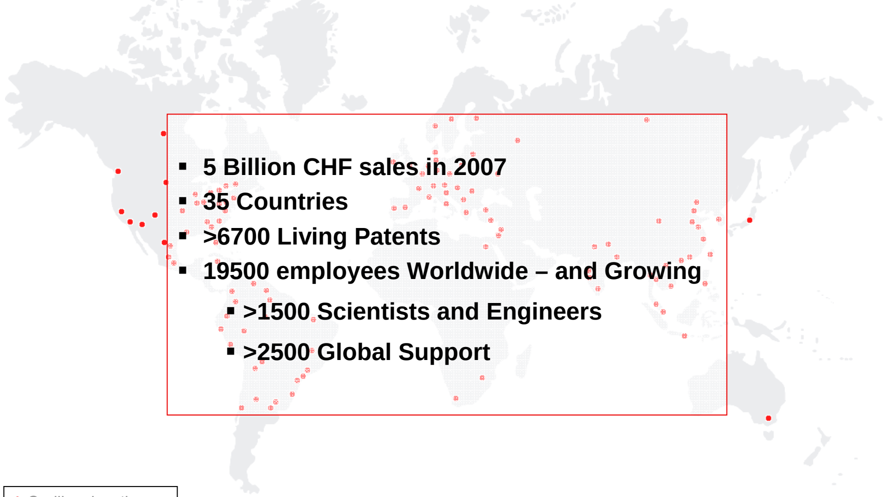
oerlikon

Oerlikon at a glance – 170 locations around the world



- 5 Billion CHF sales in 2007
- 35 Countries
- >6700 Living Patents
- 19500 employees Worldwide – and Growing
  - >1500 Scientists and Engineers
  - >2500 Global Support

● Oerlikon locations

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Executive Board OC Oerlikon AG

Dr. Uwe Krueger

CEO

Dr. Joerg Eichkorn

CFO

Bjoern Bajan

General Counsel

Jeannine Sargent	Dr. Hans Braendle	Thomas Babacan	Dr. Carsten Voigtlaender	Dr. Marcello Lamberto	Gary Lehman	Kurt Trippacher
CEO Oerlikon Solar	CEO Oerlikon Coating	CEO Oerlikon Vacuum	CEO Oerlikon Textile	CEO Oerlikon Graziano Drive Systems	CEO Oerlikon Fairfield Drive Systems	CEO Oerlikon Components

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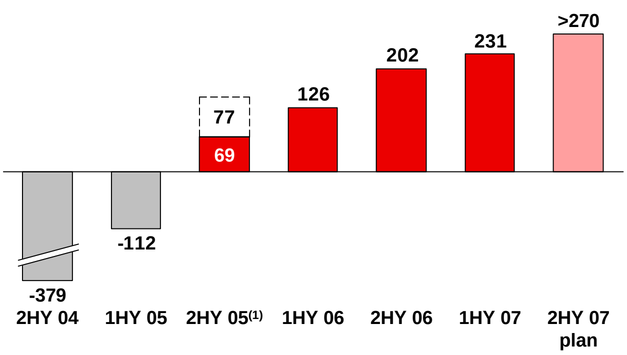
Sustainable EBIT improvement since 1HY 2005

(in CHF m)

Semi-annual EBIT development



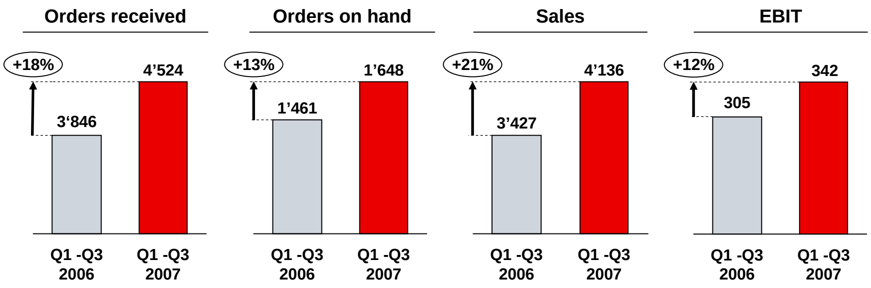
Strong 2nd half year 2007 expected

(1) EBIT 2005 w/o sale of Inficon

oerlikon

Double digit growth in the first 9 months of 2007 (1)

(in CHF Mio.)



(1) Oerlikon incl. former Saurer Group on a pro-forma basis January – September 2006

oerlikon solar

Agenda

- Oerlikon Overview
- Oerlikon Solar as Technology and Market Leader
- PV-Solar Driver: Cost Reduction

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Our Mission

oerlikon solar

Oerlikon as First Mover

Milestones

Sept 03	Oerlikon Solar R&D Lab with Dr. J. Meier and Dr. U. Kroll, cooperation with IMT
June 04	First 1.4m^2 a-Si thin-film module presented
Dec 04	Research facility delivered to SCHOTT Solar, start of joint development
May 06	TÜV Rheinland 1,4m^2 module tests passed
Dec 06	40 MW facility delivered to **Ersol** Thin Film
July 07	Start of ramp-up of the ersol Thin Film line first modules reach nominal power on-time
Sept 07	Introducing Micromorph Tandem (9+% stab.)
Oct 07	40 MWp ramp-up at **SCHOTT** Solar

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oerlikon solar

Strong and Highly Motivated Team

Dec 2003	20 employees
Dec 2004	28 employees
Dec 2005	82 employees
Dec 2006	140 employees
Dec 2007	200 employees

oerlikon solar

Agenda

- Oerlikon Overview
- Oerlikon Solar as Technology and Market Leader
- PV-Solar Driver: Cost Reduction

oerlikon solar

Solar Technology Driving Force: Cost Reduction

- **Cost Reduction**
  - **Productivity Up**
    - Up-time Up
    - Yield Up
    - Throughput Up
    - Automation Up
    - Manuf. Steps Down
    - MP Complexity Down
  - **Performance Up**
    - Q-Efficiency Up
    - Nr.-Junction Up
    - Light Trapping Up
    - Interfaces Adjustment UP
  - **Investment Down**
    - Equipment $ Down
    - Consumable Down*
    - Footprint Down
    - Utilization Up

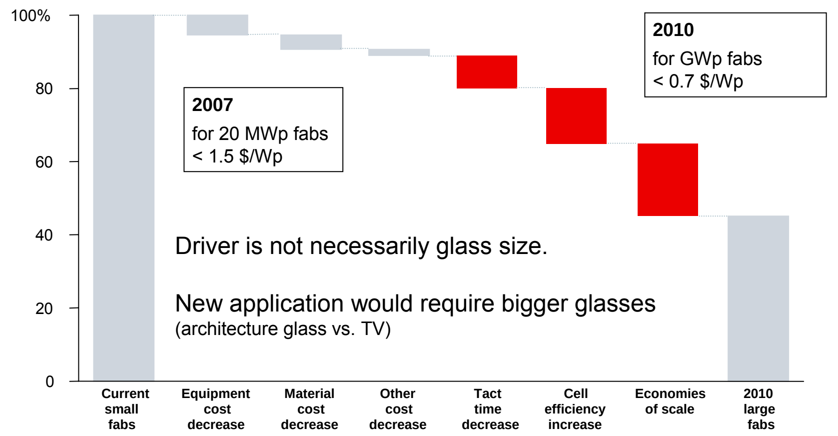
Glass size

Standardization

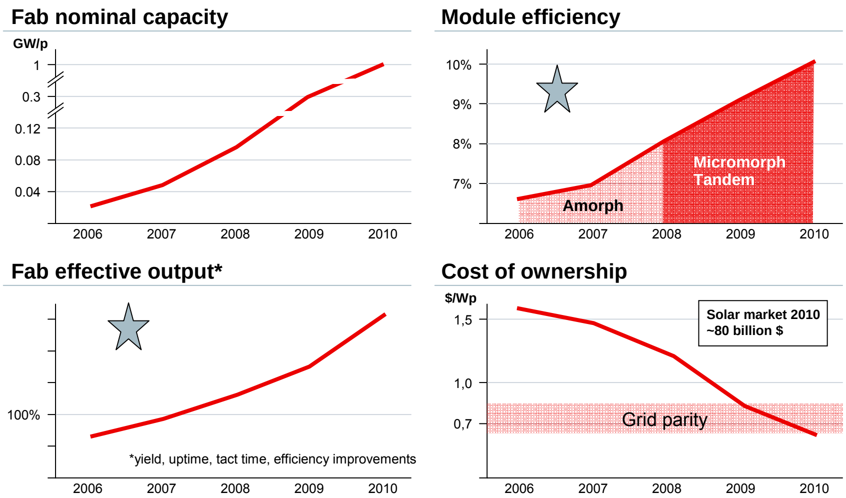
oerlikon solar

Cost of Ownership Development to Grid Parity

Amorph 2007 to micromorph tandem 2010

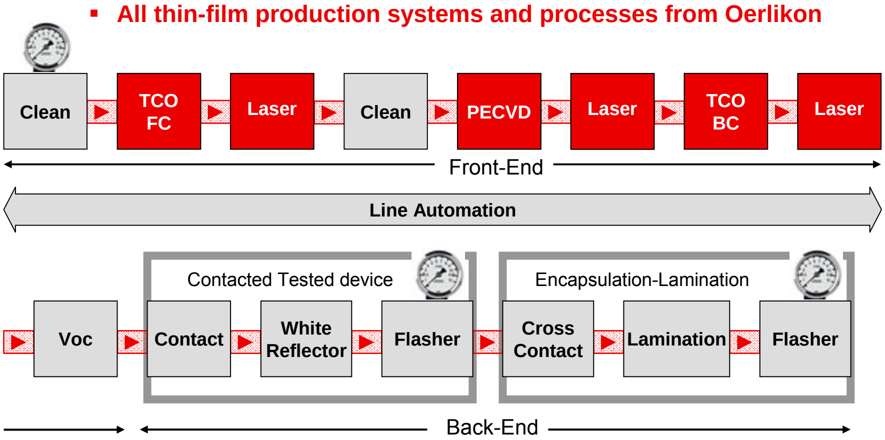


Solar - Achieving Grid Parity



FAB 1200 – End-to-End Turnkey Production Solutions

- **All thin-film production systems and processes from Oerlikon**



Challenges for Vacuum Systems Manufacturers in the PV Industry

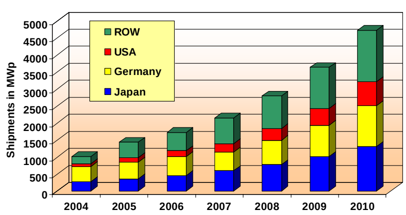
Michael Liehr
Leybold Optics Dresden

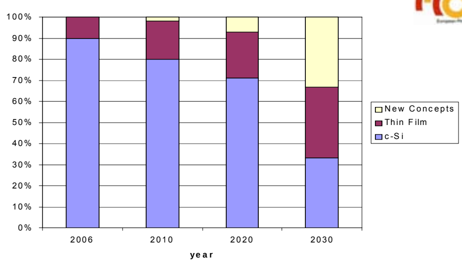
LEYBOLD OPTICS

Trends & Motivation

LEYBOLD OPTICS

- Unrivalled market growth over the past years
- Subsedised markets, growing prices for fossil fuels
- Global warming becoming focus of politics
- Growing market share for thin film technologies
- Thin film PV needs high percentage of vacuum based technologies





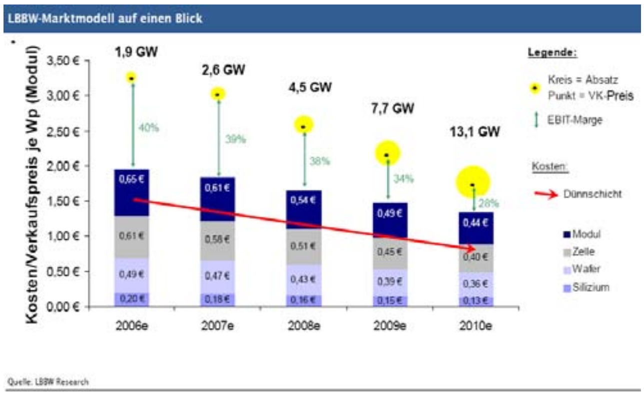
Market Development

LEYBOLD OPTICS

➢ Further market growth only by significant cost reductions

➢ Reductions of EBIT/ margin seems inevitable

➢ Thin film PV will take the same course as wafer based PV



Market Development

LEYBOLD OPTICS

Photovoltaics:
- The price problem -

• PV market will continue to be artificial for the time being

• Price increase for fossil and nuclear fuels may be helpful for PV

• Thin film PV has higher potential for cost reductions

• Thin film solar cells have shorter energy payback cycles

LBBW-Prognosen für Nachfrage und Preis

Neu Installationen in MWp	2004	2005	2006e	2007e	2008e	2009e	2010e	CAGR 06e-10e
Potenzielles Angebot (MWp)		1 500	2 007	2 912	5 422	9 833	15 885	68%
Modulpreis (€)	3,20	3,25	3,25	2,99	2,63	2,21	1,86	-13%
Preisentwicklung		1,6%	0,0%	-8,0%	-12,0%	-16,0%	-16,0%	
NACHFRAGE								
Deutschland	610	863	1 043	1 194	1 735	2 553	3 168	32%
Italien	5	5	20	125	350	690	1 362	187%
Spanien	10	25	85	250	493	536	1 264	96%
Sonstiges Europa	18	30	60	100	225	425	800	91%
Europa	**643**	**923**	**1 208**	**1 669**	**2 804**	**4 204**	**6 594**	53%
USA	90	90	140	284	584	1 348	2 532	106%
Sonstiges Amerika	15	23	35	50	85	150	275	67%
Amerika	**105**	**113**	**175**	**334**	**669**	**1 498**	**2 807**	100%
China	12	10	30	35	100	225	500	102%
Indien	2	10	25	30	60	120	250	78%
Japan	272	280	290	305	385	643	1 238	44%
Südkorea	3	7	20	75	175	325	550	129%
Sonstiges Asien	10	20	45	60	110	175	300	61%
Asien	**299**	**327**	**410**	**505**	**830**	**1 488**	**2 838**	62%
Rest der Welt	20	35	75	125	250	500	850	83%
Gesamt	**1 067**	**1 397**	**1 868**	**2 634**	**4 553**	**7 690**	**13 089**	63%
yoy		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

Quelle: LBBW Research

Market Development

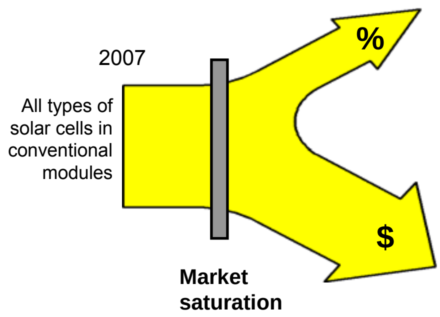
LEYBOLD OPTICS

High efficiency branch:

- smaller part of the market
- efficiency is technology driver
- some thin film technologies may be competitive

BIPV (building integrated photovoltaics) branch:

- larger part of the market
- Wp costs are technology driver
- large sized cells in flexible modules (or cheap conventionel type modules)



High efficiency

- crystalline cells
- tandem/triple Si tf cells
- CIGS cells

... in conventional modules

„BIPV“

- cheap Si TF cells
- cheap CIGS cells
- cheap CdTe cells
- cheap …

...in cheap modules

Challenges

LEYBOLD OPTICS

Three Challenges

- „Turnkey“ Solutions (f. thin film solar cells)
- Reduction of production costs
- New solar cell/module concepts

„Turnkey“ Solutions

LEYBOLD OPTICS

- Silicon thin film has longest history but lowest potential for high efficiency
- CIGS has highest efficiency potential. Indium price problem/shortage may only be of a speculative nature
- CdTe suffers from a a bad reputation (Cd cancerogenic) but now leads the race for the lowest price per Wp (First Solar)

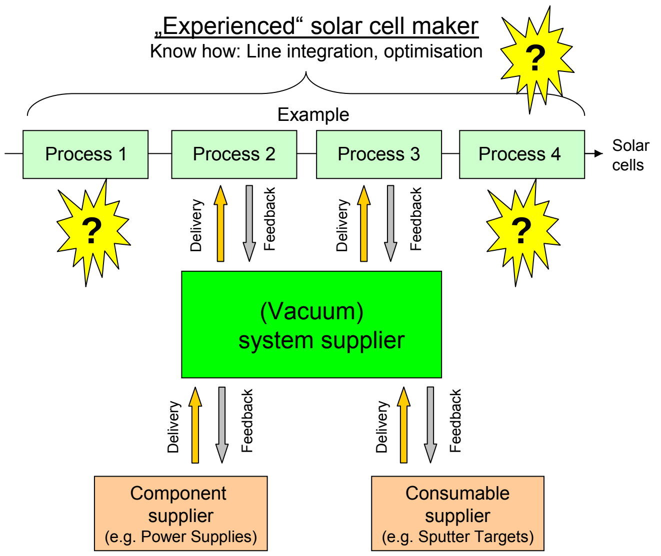
TF solar cell type	Module efficiency range	Capacity 2006 approx	Module/Cell Makers
a-Si(/µc-Si)	6-7% (8-9%)	193 MWp	Kaneka Mitsubishi HI Sharp Schott Solar Free Energy Europe ...
CdTe	7-9%	86 MWp	First Solar Antec Solar Energy ...
CI(G)S	9-11%	74 MWp	Würth Solar Avancis Global Solar Energy Honda Sulfurcell ...

Source: ZSW, Stuttgart

„Turnkey“ Solutions

LEYBOLD OPTICS

- (Vacuum) systems manufacturers do not have sufficient know-how in highly efficient „Turnkey“ factories
- Research institutions often offer only lab processes which have not been tested sufficiently in production environments
- The dynamics of the thin film PV market does not give much time to develop new technologies thoroughly



Cost Reduction

LEYBOLD OPTICS

- There are two major obstacles on the way to serious cost reductions

-- missing standards in size

-- missing mainstream technologies

➢ There are almost no worldwide accepted standards in substrate size (rigid and flexible)

Glass: 910x910 mm², 455x910 mm² , 1400x1100 mm², 600x1200 mm², 800x1300 mm², 300x1200 mm², 600x900 mm² , 650x1250 mm²,...

Web: 10 mm Cu web, 300 and 600 mm steel web & polymer...

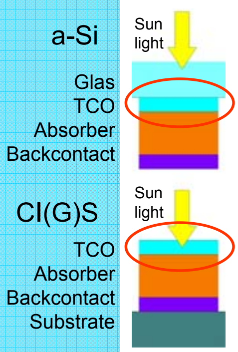
➢ Too many competing processes for making thin film solar cells

Established or still under development: PECVD, MOCVD, (co)-Sputtering, (co)-Evaporation, Paste, Inkjet, Electroplating, Nanoparticle/Sol-Gel etc.

Cost Reduction

LEYBOLD OPTICS

TCO performance is crucial for the struggle towards higher solar cell efficiencies



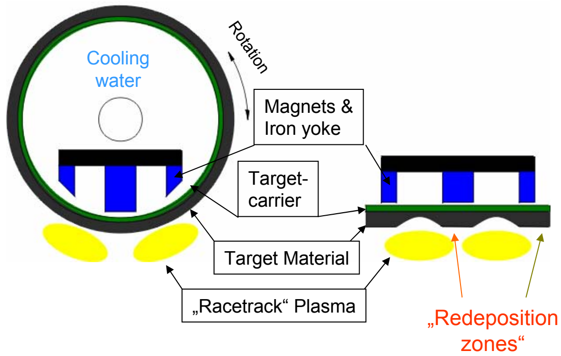
TCO Material	Growth Method	Resistivity [µΩ*cm]	Know-how base	Comments
SnO_2:F	APCVD	500-2000	Glass makers	commercial, textured, not optimised for solar cell, corrosion resistant, H plasma etch sensitive
ZnO:B	LPCVD	1600-2000	Solar Cell/Equipm. makers	established, textured, sensitive to acidic/basic sol.
ZnO:Al	Mag. Sputtering	300-800	Solar Cell/Equipm. makers	established, requires texturing, senstive to acidic/basic solution
In_2O_3/SnO_3	Mag. Sputtering	150-250	Equipment maker	best material, too expensive
Zn_2SnO_4	Mag. Sputtering	5700	Research Institute	under investigation

Cost Reduction

LEYBOLD OPTICS

- Cylindrical magnetron sputtering cathodes have reached mature stage
- Rotation of target, power transfer and cooling are industrially viable
- Target manufacturers have understood the significance of this technology
- Not every material is suitable as cylindrical targets

Magnetron Sputtering



Cost Reduction

LEYBOLD OPTICS

Magnetron Sputtering

Planar Sputter Magnetron
with $ZnO:Al_2O_3$ target

- mature technology
- no moving parts

Cylindrical Sputter Magnetron
with $ZnO:Al_2O_3$ target

- much higher target utilisation
- much higher sputter rates
- no re-deposition zones
- TCO resistivity not subject to target lifetime

Cost Reduction

LEYBOLD OPTICS

- Using cylindrical $ZnO:Al_2O_3$ targets reduces material costs about 40% (as of 01/07)
- 2-3 times higher deposition rates saves investment costs

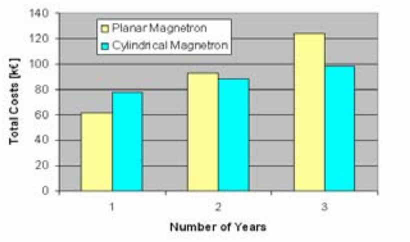
Cylindrical Sputter Cathode		Planar Sputter Cathode	
($ZnO:Al_2O_3$ 2%)			
Layer thickness:	600 nm	Layer thickness:	600 nm
Target length:	750 mm	Target length:	750 mm
Backing tube ID:	5"	Target width:	250 mm
Target thickness:	14 mm	Target thickness:	14 mm
Target utilisation:	75%	Target utilisation:	25%
Dynamic dep. rate:	< 150 nm m/min	Dynamic dep. rate:	< 140 nm m/min*)
Collection efficiency	80%	Collection efficiency	80%
Power	15 kW	Power	15 kW

*) double racetrack

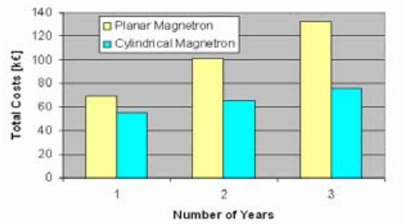
Cost Reduction

LEYBOLD OPTICS

- Costs for magnetron and targets, accumulated for 1,2 and 3 years of operation respectively
- Significant reduction of investment and consumable costs for cylindrical magnetron cathodes within one year



Situation: 01/2006



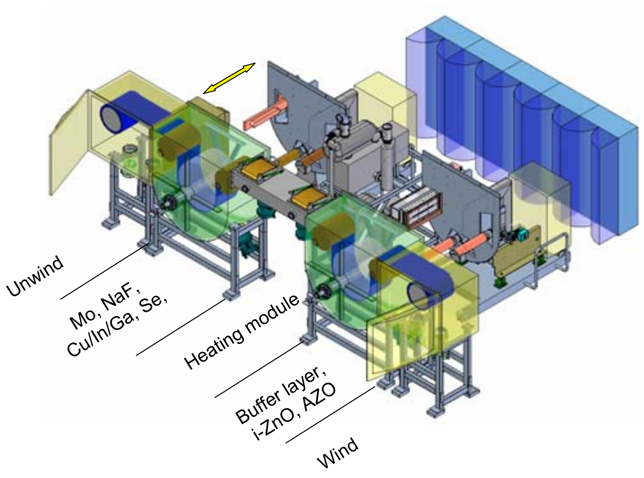
Situation: 01/2007

New Solar Cell/Module Concepts

LEYBOLD OPTICS

- „All-in-one" solution for CIGS on flexible substrates
- no monolithic series connection
- Length of substrate 1000-4000 m
- Change of substrate witout venting entire machine

Concept for CIGS solar cells on metal strips



Conclusions

LEYBOLD OPTICS

- There are still some efforts necessary to bring all major thin film solar cell production know-how to the vacuum systems manufacturer community
- It is imperative to cut the costs for solar cell production equipment (~30% by 2010)
- New solar cell and module concepts will be needed to establish PV as a lucrative supplier of electrical energy

Thin Film Photovoltaic Production Technology

Udo Willkommen
Martin Dimer

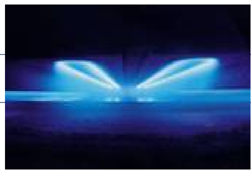
VON ARDENNE Photovoltaik
GmbH & Co. KG

Outline

- Brief company portray
- Different kinds of equipment
- Driver of cost's for a thin film production
- Advantages of rotatable magnetrons
- Example for metal or TCO coating
  - Different sizes of substrates
  - The effort of substrate scaling
- Conclusions

Corporate Expertise

Technologies



Plasma

Electron Beam

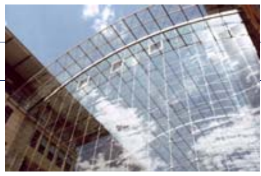
Corporate Expertise

Industrial Vacuum Processes

Customized Equipment for

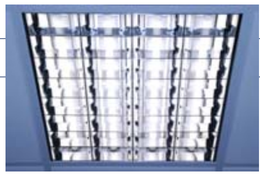
Production
Pilot
R&D

Strategic Business Fields



Architectural Glass

Photovoltaics

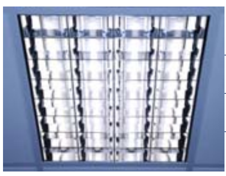


Metal Strip

Applications

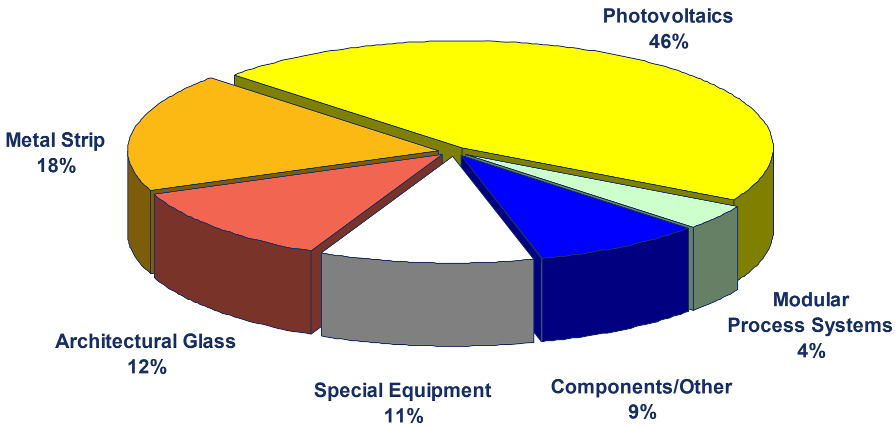

Architectural Glass
Photovoltaics


Automotive
Display




HR Mirror
Solar Absorbers

Business 2006



Characteristic Differences between wafer based and thin film Solar Cells

	Wafer based solar cells	Thin film solar cells
Substrate size [m²]	0,024	0,72...5,7
Cycle time per substrate [sec]	2...4	60...600
Efficiencies [%]	14...20	5...13
Contact layers	screen print plating	vacuum coating
Absorber	thermal and chemical processes	mainly vacuum coating
Passivation- and antireflexion layer	vacuum coating	
Modul concept	connection in series	integrated connection in series

Vacuum Process Technology

Electrical contacts	Absorber	Passivation Antireflection
Al, Ag, NiV, Mo, Sb_2Te_3, ITO, ZnO:Al i-ZnO	a-Si:H, µc-Si:H, **CuGa, In,** Se, S, **CdTe**	SiN_x:H
Sputtering Evaporation	PECVD Evaporation Sputtering	PECVD (Sputtering)

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Different kinds of equipment

Examples of glass coating machines

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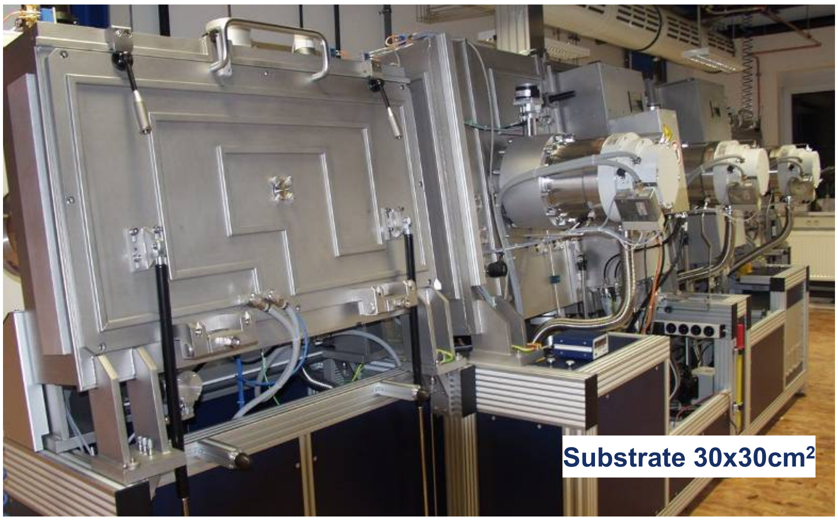
Clustersystem CS 730 for R&D

VISS 300 for R&D



Glass Coater GC 60 H for pilot line production

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Glass Coater GC 60 V

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VON ARDENNE

Glass Coater GC 60 V

Glass Coater GC 120V

GC 120 H for pilot line production

GC 175 V production tool

Architectural Glass Coater GC 321 H

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Architectural low-E Coater GC 321 H

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Driver of cost's for a thin film production

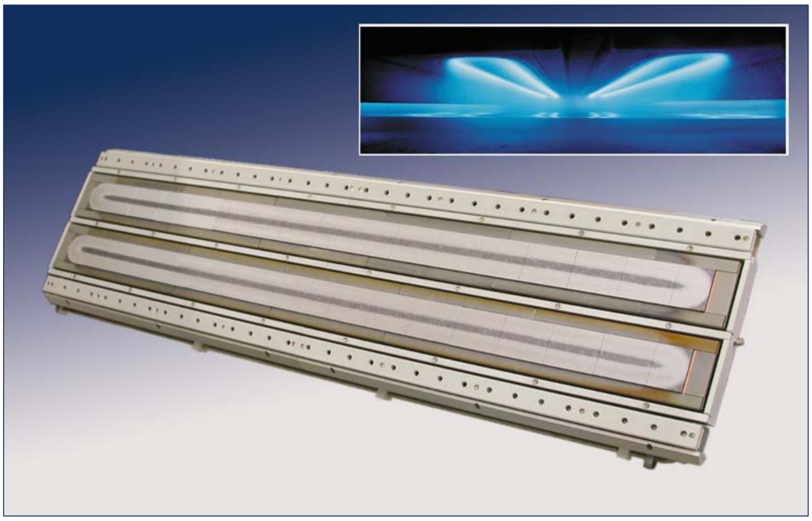
- 60 to 70% target material
- Consumption of high purity medias
  - Clean room area
  - DI water
  - Process gases
- High skilled people
- Maintenance of coating machines

What can we do to reduce the operational cost`s?

What can we do to reduce the operational cost`s?

- Increasing of utilization of the target material
- Longer campaign time without interruption
- Bigger substrate formates
- Carrier free transport
- Low maintanance times
- High availibilty of the coater

Dual Magnetron Sputtering



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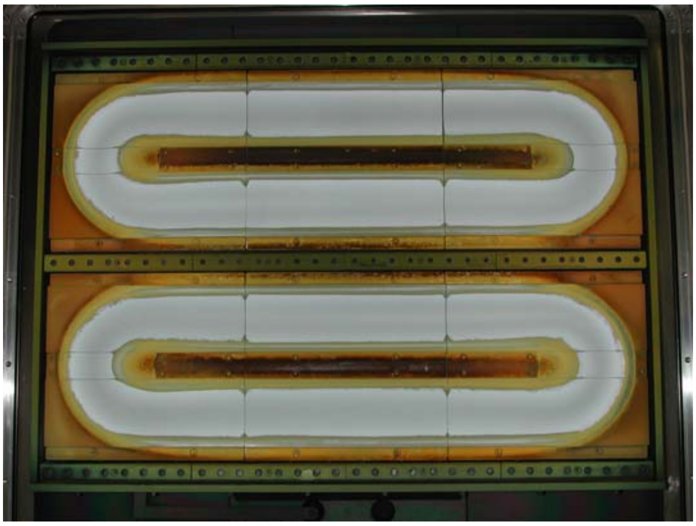
WSM 900 with Zn:Al Metal Targets DC-DC mode, after 1.500 kWh



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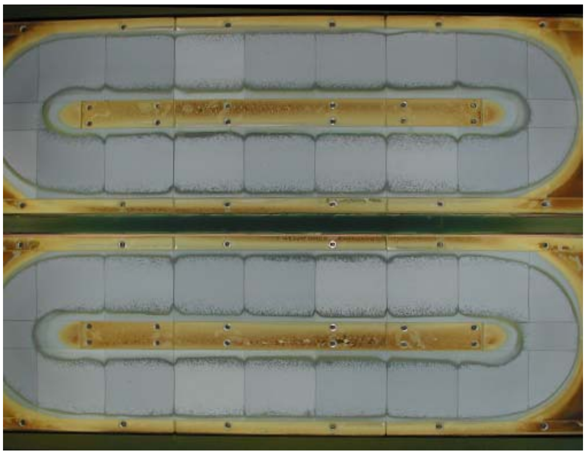
WSM 900 with ZAO Ceramic Target
DC-DC mode, Targets 240 x 900 mm²



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Large Area WSM-type Magnetron
for Glass Coating applied

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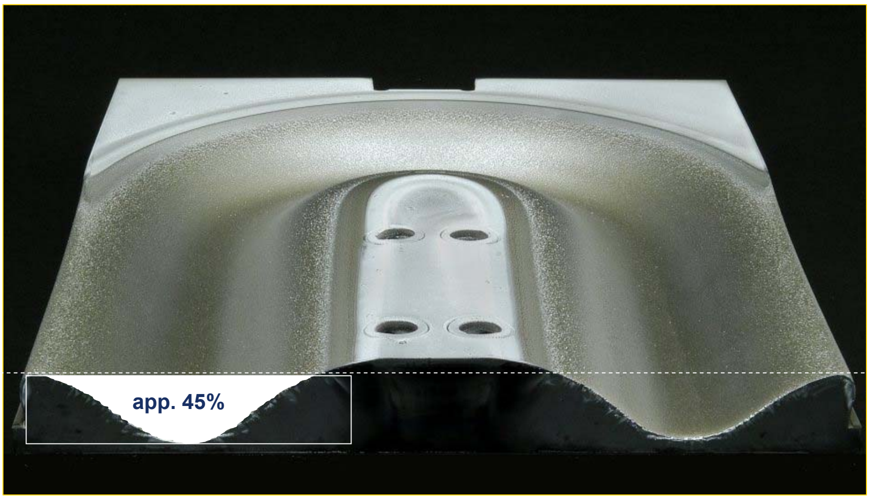
Sputter Process with Planar Magnetron

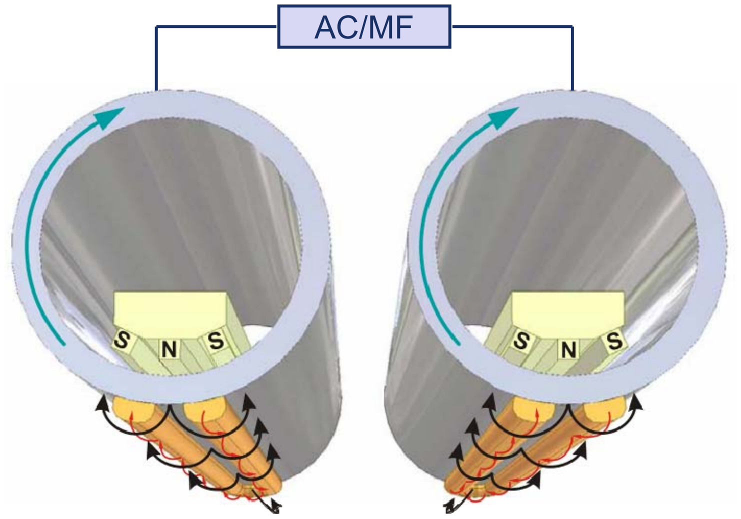
Utilization: ≤ 45%

Usable width up to 4m

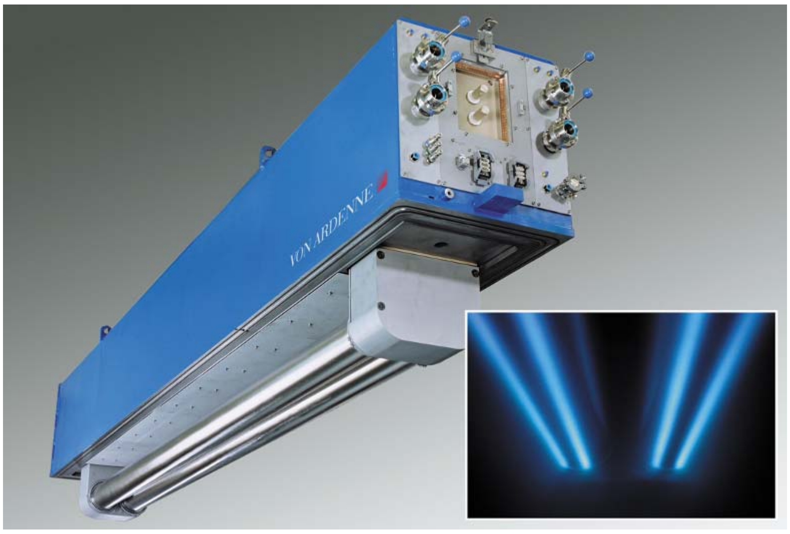
WSM Magnetron
Target Erosion



Dual Rotatable Magnetron Process



Dual Rotatable Magnetron for Large Area Coatings



Dual Rotatable Magnetron Reactive Sputtering with Cr Target

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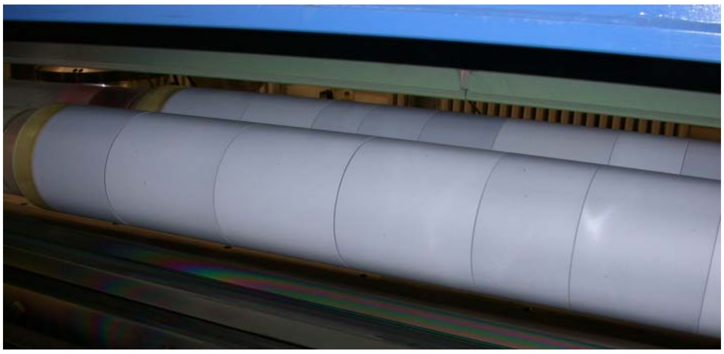
ZnO:Al Ceramic Tube Target (2%-Al_2O_3)



Advantages with Rotatable Magnetrons

- Large material stock for long campaign durations
- High power density for high deposition rates
- No compound debris / flaking from target surface
- Very high target utilization (80%)

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VON ARDENNE

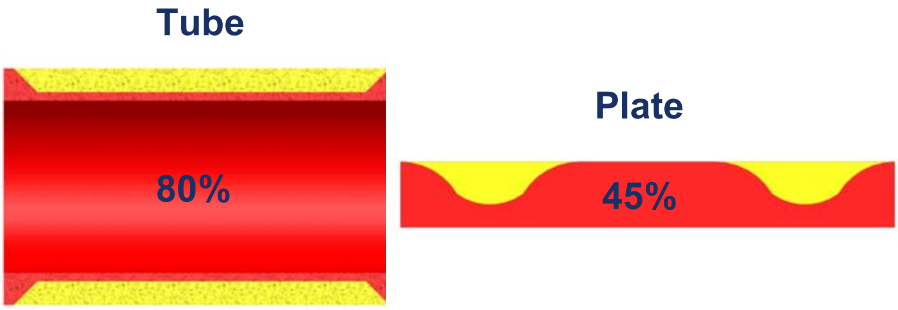
RSM/RSM 1300 Rotatable Magnetron mit Mo-Rohrtarget

RSM/RSM 1300 Rotatable Magnetron with DAS and ZAO-Target

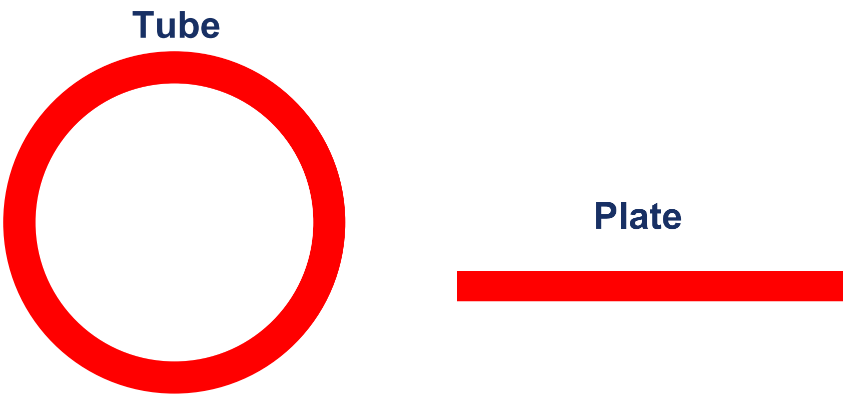
Sputter Process with Rotatable Magnetron

Utilization: ≤ 80%

Utilization of target material



Reservoir of target material

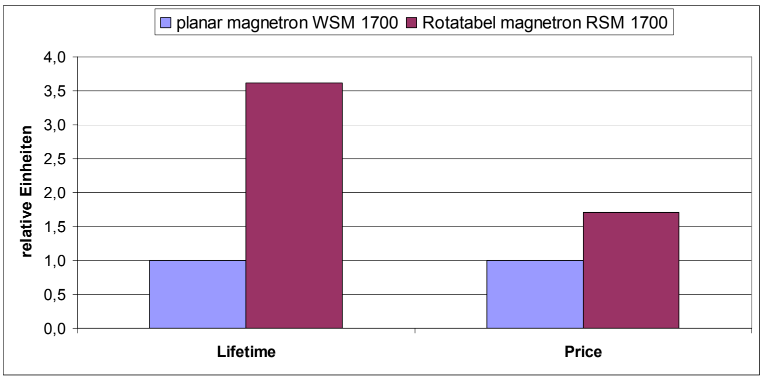


Circumference=3,14 * diameter

In Reallity 3,5 times more

Comparison planar Magnetron and Tube Magnetron

ceramic $ZnO:Al_2O_3$ Target



- tube cathode: high pool of material and high utilization of the target (70...80%) lead to high cost reduction compared to the planar target

Scale of Production Processes on large Surfaces
Development of Costs

Example: deposition of ZnO:Al from ceramic tube target

- **Process:** sputtering with tube magnetrons in horizontal systems
- **Substrates:** 1,4m² (Gen 5) → 5,7m² (Gen 8.5)
  → 19,8m² („Jumbo-Format“ in architectural glass coating)
- **Layer thickness:** 1000nm
- **Cycle time:** 60sec
- **Substrate temperature:** 200°C
- **Investment write-off:** linear, 7 years
- **10% efficiency** for estimation of anual production capacity (MW_p)
- **Target cost reduction** by using large quantities in mass production is not considered

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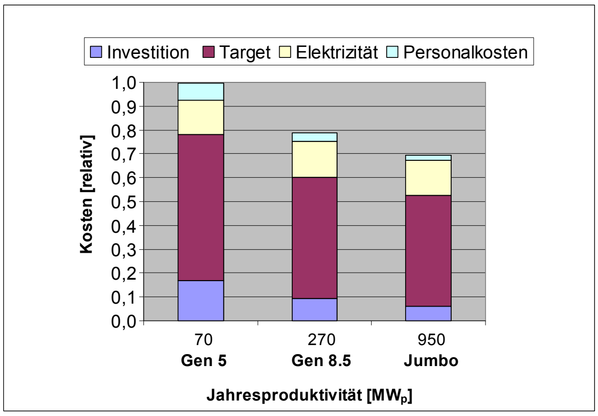
Cost Reduction by Extension of Substrate Surfaces
Sputtering of ZnO:Al

- **30% cost reduction by scaling on large surfaces**
- **60 – 70% costs for Targets**
- **10 - 15% investment costs in vacuum coating system**
- **possibility of further cost reduction via thicker ceramic or metallic targets**



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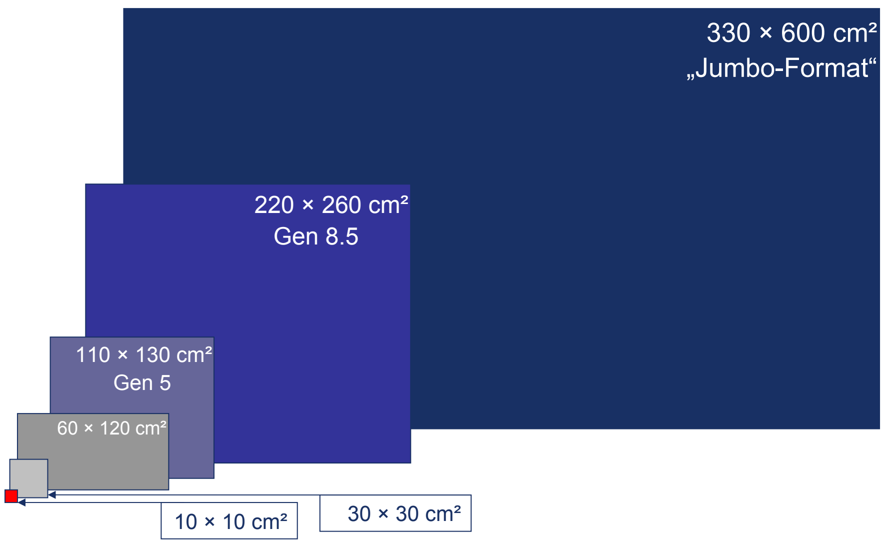
Summary

- Scaling of large substrate formats shows a further possibility to cut production costs (if the technologies allow it)
- Example: production technology to deposit transparent conductible contact layers basing on ZnO:Al
  - In mass production operating costs (targets) define production costs up to 60 to 70% (CoO)
  - Scaling of large surfaces allow cost savings of more than 30%
  - Sputtering of thicker ceramic targets or metallic ZnAl-Targets could lead to further cost reductions
- Scalable, quick and in consumables well-priced production technologies can make an important contribution to further cost reduction in the mass production of solar cells

Substrate Sizes



Substrate Formate

Company	Technology	actual substrate format in mm	futural substrate format in mm
Antec Solar Energy	CdTe	1200x600	
Calyxo	CdTe		
First Solar	CdTe	1200x600	
CSG	TF-c-Si	1250x1100	
ErSol Thin Film	a-Si	1200x1100	
Brilliant 234	a-Si		
NUON	a-Si		
Schott Solar	a-Si	1300x1100	
Signet solar	a-Si	2.2 x 2.6	
VHF Technologies GmbH	a-Si		
Avancis	CIS	1220x305	
Johanna Solar	CIS	1200x500	
Odersun	CIS		
Scheuten Solar	CIS		
Solibro GmbH	CIS		
Sulfurcell Solartechnik Gmbh	CIS	1200x600	
Würth Solar	CIS	1200x600	

Thank you for your attention!

signet solar™

Glass & Module Size for Thin Film Solar

K.-H. Stegemann
VP Technology

EPIA 3rd “Thin Film Workshop”
November 22 & 23 / 2007

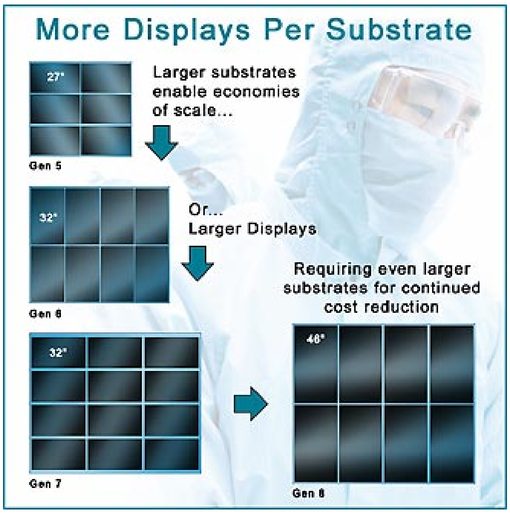
clean affordable renewable energy™

Glass & Module Size Thin Film

- Glass size
- Equipment up-scaling
- Module size

Economy of Scale for LCD Technology

- Glass Thickness 0.7mm
- G5 1.10mx1.30m
- G7 1.87mx2,20m
- G8 2.20mx2.50m
- G9 2.40mx2.80m
- G10 2.85mx3.05m
- Status
- G8 production
- G10 planning Sharp



Source: Corning 09/2007

Economy of Scale for LCD Technology

Summary for LCD displays

- Specific glass size & production (no loss)
- On side glass production (Corning)
- Specific equipment market
- Cost reduction by up-scaling

Conclusion for Si thin film PV

- Si Thin film is connected to LCD market
- More and larger PV modules per substrate

Status Thin Film

- Status module production

Schott Solar	Kaneka	Sharp	CSG Solar	Würth Solar	First Solar	Antec Solar
a-Si	a-Si	a-Si/µ-Si Tandem	tf-c-Si	CIS	CdTe	CdTe
ASI-F90	G-EA060	NA-901WP	CSG 100	WS 11007/80	FS-272	ATF 50
1,1mx1,3m	0,99mx0,96m	1,13mx0,93m	1,25mx1,10m	1,2x0,6m	1,2mx0,6m	1,2mx0,6m

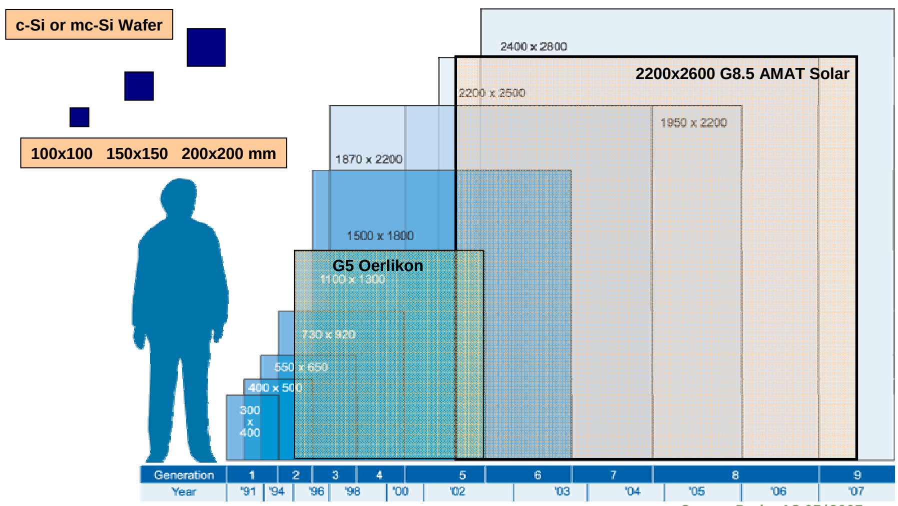
- Status equipment for a-Si/µ-Si thin film

Oerlikon	AMAT	Ulvac
a-Si/µ-Si Tandem	a-Si/µ-Si Tandem	a-Si
1,1mx1,3m	2,2mx2,6m	1,1mx1,4m
G5	G8.5	G5.5

- Equipment from LCD

Substrate Size Roadmap for TFPV

- Si Wafer versus Glass Size (Generation 1 to 9 Flat Panel Industry)

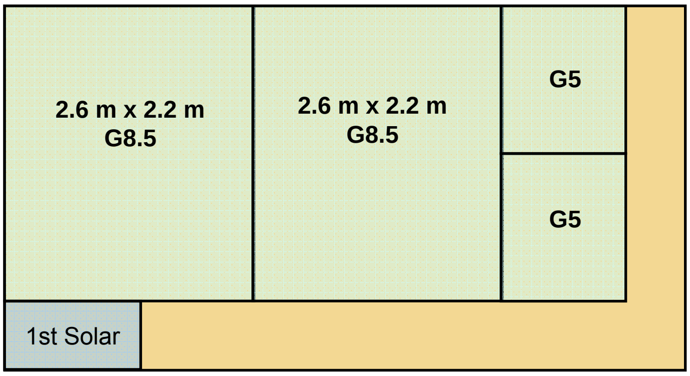


Source: Basler AG 07/2007

Float Glass Size

- Architecture glass size (Europe)

3.21 m x 6.00 m



- Back Glass ~ 40% glass loss for G8.5; 25% for G5
- NSG TCO Glass ~ 20% loss

Optimal Module Size

- Cost Reduction by up-scaling for 60MW line

Glass Size	1.2x0.6m	1.1x1.3m	2.2x2.6m
Invest	1		
Transportation	1		
Handling	1		
Packaging	1		
Mechanical strength	1	Glass 3.2mm (4)?	Glass 3.2mm (4/5)?
Mounting strength	1	Back bars ?	Back bars
Cables, j-boxes	1		
Weight (kg)	12	25	99
Mounting frames	1		?
Mounting effort	1		?
Maintenance	1		?

Summary

- Detailed calculation are necessary
  - Production cost per Wp
  - BOS cost per Wp
- Mechanical and mounting issues?
- Specific glass production for PV
- Optimal glass size for production G8.5?
- Optimal module size for BOS G5?

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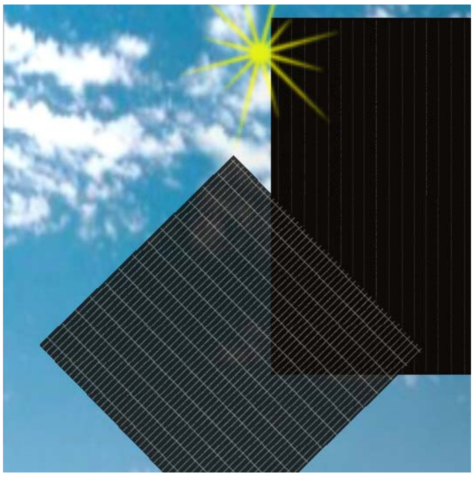
www.signetsolar.com

November 22 & 23/2007 EPIA 3rd Industry Workshop 2007 signet solar



3rd International Photovoltaic Industry Workshop on Thin Films

22 & 23 November 2007
JRC/IES, Ispra, Italy

Silicon Thin Film PV Technology @ Schott Solar

Hermann Maurus
Schott Solar GmbH
http://www.schott.com/solar

SCHOTT solar

Outline

- Introduction to SCHOTT AG and SCHOTT Solar GmbH
- Thin film Production at Schott Solar
- Future developments
- Market segments and product size
- Keyword is "cost"

SCHOTT solar

SCHOTT AG at a glance

Advanced Materials

Electronic Packaging *

Fiber Optics

Flat Panel Display

Home Tech

Microlithography

Optics for Devices

Pharmaceutical Systems

Solar

- 2 Billion Euro Sales worldwide
- 17.000 Employees in 37 Countries
- Founded: 1884
- Owner: Carl-Zeiss-Stiftung

SCHOTT solar

17.11. 2007, HM

SCHOTT AG

SCHOTT Solar GmbH
Mitarbeiter: 900 (2006)

SCHOTT Solar GmbH

SCHOTT Solar, Inc.
Billerica (MA) USA
Vollintegrierte Fertigung von Wafern, Zellen und Modulen

SCHOTT Solar Inc.
Roseville (CA) USA
System Integration
Vertrieb von Modulen und Systemen

SCHOTT Solar CR
Valasske Mezirici, CR
Produktion von Solarmodulen

Alzenau, Hauptsitz
R&D c-Si
Fertigung von Wafern und Zellen

Putzbrunn
R&D Thin film
Produktion von Dünnschicht-Modulen: OEM, BIPV

Jena
Produktion von Dünnschicht-Modulen: Standard-Module

SCHOTT solar

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SCHOTT solar

Thin film production at SCHOTT Solar

3 MW pilot production line in Putzbrunn

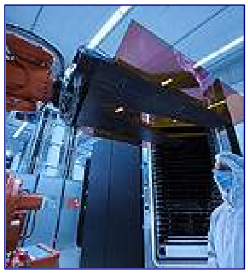
- operation since 1992
- 7/24
- equipment uptime 90%
- yield beyond 90%
- OEM, BIPV, Standard PV modules developed

SCHOTT solar

Thin film production of SCHOTT Solar

>30 MW production line in Jena

- SOP September 2007
- full production begin of 2008



Improvements from Pilot to Production

Pilot module
ASI F-32

Production module
ASI F-90

Module power	32W	86 to 100W
Module size	0,6m²	1,4m²

Improvements from Pilot to Production

Pilot module
ASI F-32

Production module
ASI F-90

Module power	32W	→	86 to 100W
Module size	0,6m²		1,4m²
Capacity	3 MW		>30 MW
Footprint PECVD	1	→	2
Laser eff. speed	1		8

Outline

- Introduction to SCHOTT AG and SCHOTT Solar GmbH
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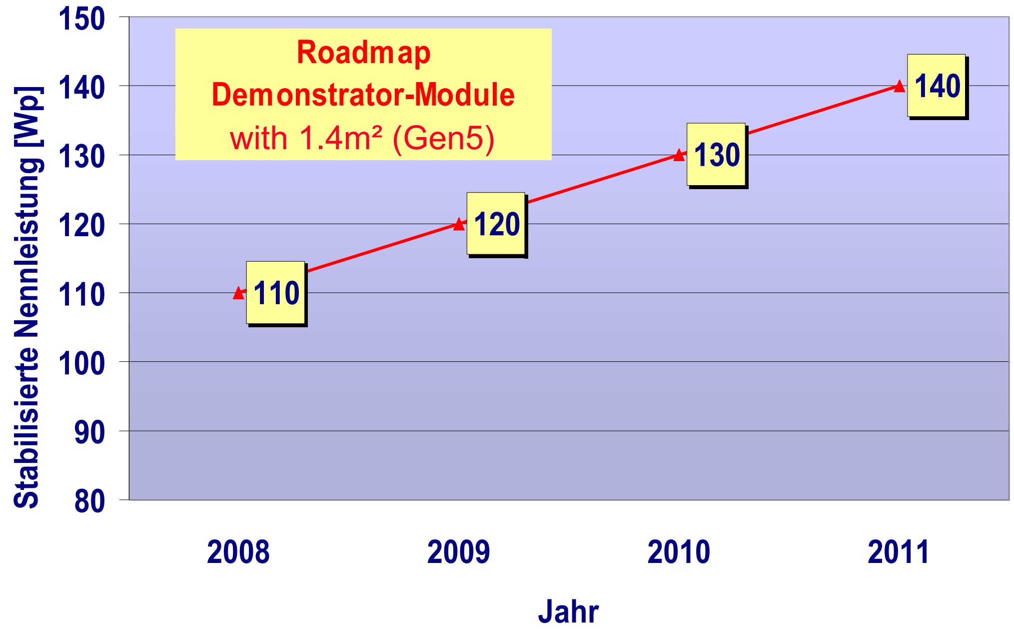
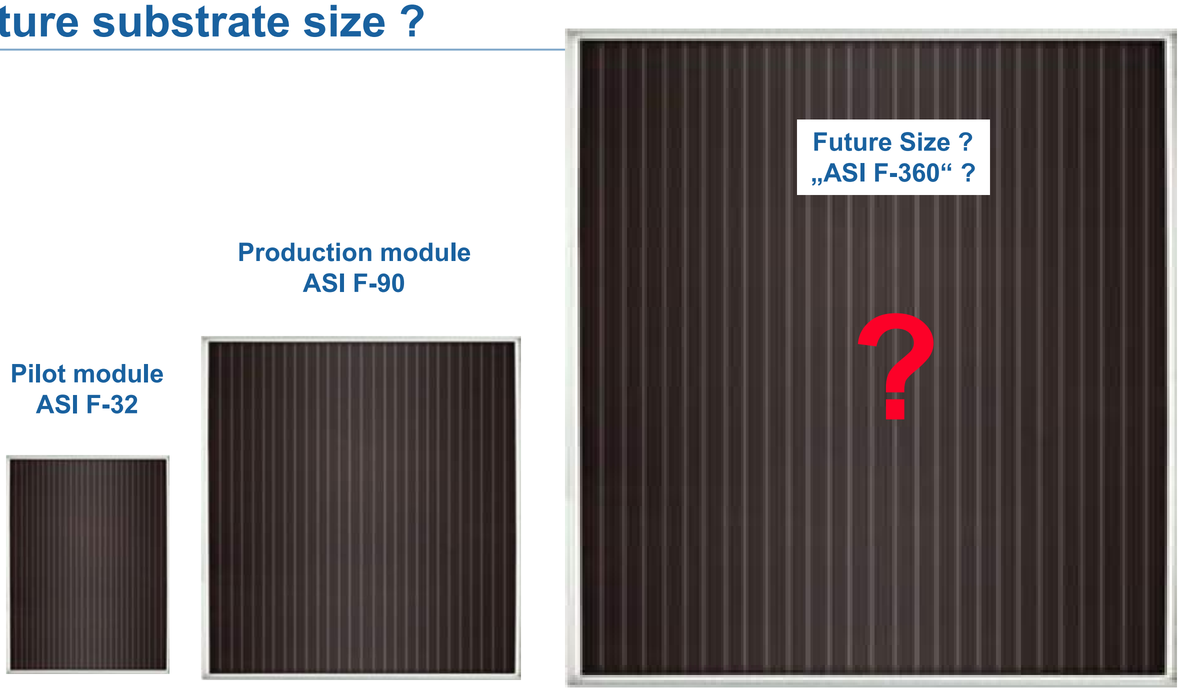
SCHOTT solar

Future development of efficiency is a “must”, because it offers strongest cost decrease!



Future substrate size ?

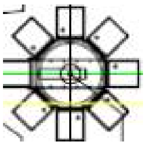


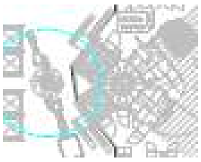
Module power	32W	86W to 100W	350W to 500W ?
Module size	0,6m²	1,4m²	5,7m² ?

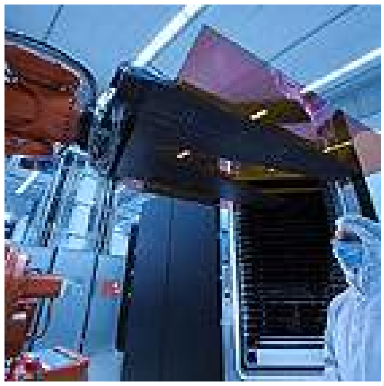
Key features of thin-film Si technology

- ...
- ...
- ...
- ...
- ...
- ...
- Synergy from large area TFT-display PECVD production equipment

  - cluster, batch, in-line
  - up to 5.7m² (Gen 8.5)







SCHOTT solar

Outline

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SCHOTT solar

ASI products: Standard Modules

Market: Roof Top PV

SCHOTT solar

17.11. 2007, HM

ASI products: Standard Modules

Market: Roof Top PV

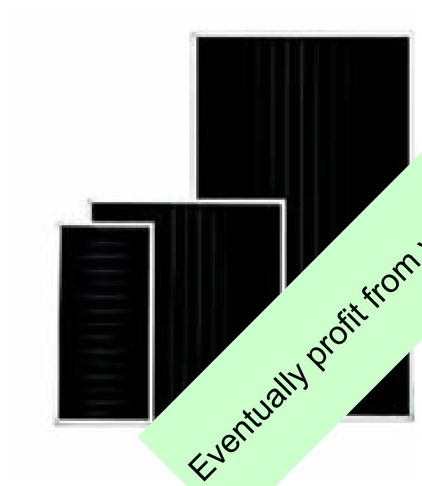
SCHOTT solar

17.11. 2007, HM

ASI products: Standard modules

Market: On Grid-Industrial

ASI products: Standard modules



Eventually profit from very large size product ?

Market: On Grid-Industrial

ASI products: Standard Modules

Market: Field installations

ASI products: Standard Modules

Market: Field installations

ASI products: OEM

Market: Off-Grid Consumer

SCHOTT solar

ASI products: OEM

No profit from very large size product.

Market: Off-Grid Consumer

SCHOTT solar

ASI products: BIPV elements

Market: Facades

SCHOTT solar

ASI products: BIPV elements

Probably no profit from very large size product ?

Market: Facades

SCHOTT solar

ASI products: BIPV elements

5000m² BIPV roof, Stillwell Train Station, Brooklyn, NYC

SCHOTT solar

ASI products: BIPV elements

This project would probably have had profit from very large product size !

5000m² BIPV roof, Stillwell Train Station, Brooklyn, NYC

SCHOTT solar

Outline

- Introduction to SCHOTT AG and SCHOTT Solar GmbH
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SCHOTT solar

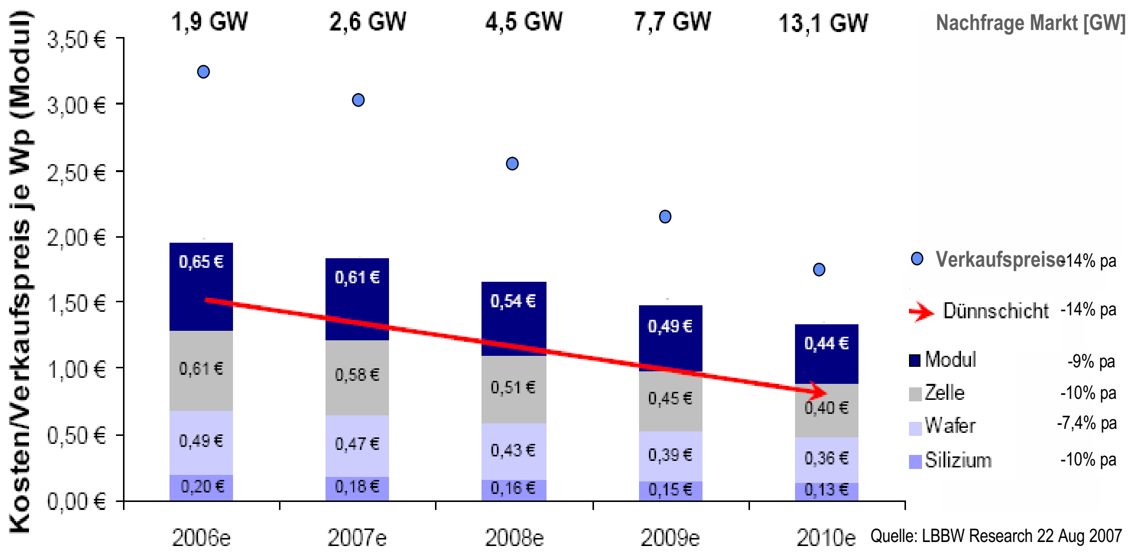
Keyword is “cost”

- Some market segments profit from larger plate size,

  but more important is
- Productivity has to be enhanced !
- Prize per Watt has to come down !!

SCHOTT solar

Keyword is “cost”



SCHOTT solar

Keyword is “cost”

Following questions have to be answered:

- Reduction on investment cost per W(capacity) ?
- Limits to efficiency, when going to very large dep size ?
- Adequate machines for all other production steps ?
- Availability and efficient usage of high quality TCO ?
- Stability of very large size products ?

…

…

- Cost per Watt of very large size products ?

SCHOTT solar

Thank you!

SCHOTT solar

17.11. 2007, HM

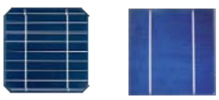
Brilliant 234. GmbH

Si Thin Film Module Production at Q-Cells

Q.CELLS

Group Organisation

Q.CELLS

Wafer-Based Technology	Core Business	Thin-Film Business
REC 17.18% ▪ Strategic partner and main supplier ▪ Technology leader in polycrystalline silicon production	▪ No. 1 independent cell player and No. 2 worldwide	**Fixed Substrates (Glass)** calyxo 93% ▪ Cadmium telluride technology
EverQ 33.3% ▪ String Ribbon technology ▪ Joint Venture with Evergreen Solar and REC	▪ Poly- and monocrystalline solar cells	BRILLIANT 234. 100% ▪ Micromorph silicon technology
SOLARIA 33% ▪ Low-concentration PV technology	▪ Next generation high-efficiency cell concepts in development	SOLIBRO 67.5% ▪ CIGS technology
		csgsolar 21.71% ▪ Crystalline silicon on glass
		Flexible Substrates flexcell 51% ▪ Amorphous silicon on plastic foil (“flexcell“)

Leader in core business with a strong focus on new technologies

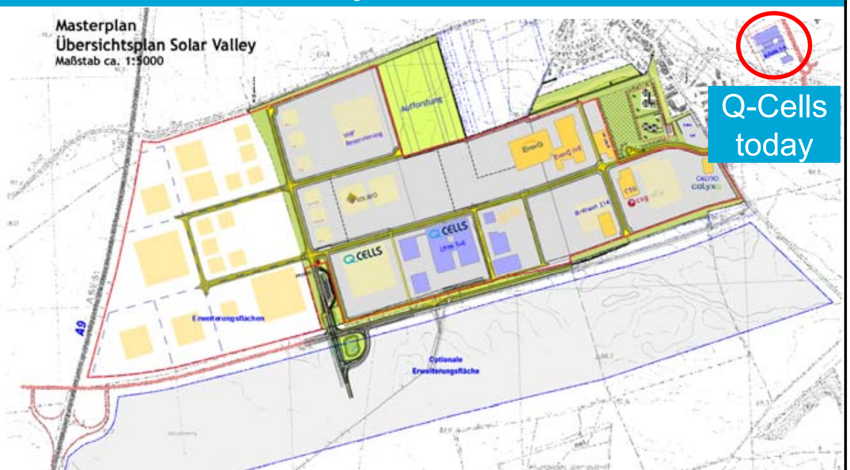
Q.CELLS

Strategy: Thin-Film Technologies

	Laboratory <1 MWp	Pilot factory 10-30 MWp	Scaling Up >50-100 MWp per unit
BRILLIANT 234.		Almost ready to rumble	Decisions to be taken by end 2007/ 2008 based upon operational results
calyxo		Early Pilot Production	
SOLIBRO		Under Construction	
flexcell		Under construction	
csgsolar		Prolonged Test production	

Q.CELLS

Overview Solar Valley



- Area: approx. 77 hectare
- Number of companies (today): 9
- Number of employees until 2010 (in total): > 5,000

Q.CELLS

Thin-Film Technologies: Subsidiaries
Brilliant 234. – Perspectives

BRILLIANT 234.

- Best efficiency in lab: 12%
- Efficiency : short-term target: 8%, mid-term target 10%
- Employees as of now: 75

Q.CELLS

Thank you.

Q.CELLS

Q-Cells: The Next Step

PAGE 7
3rd Int´l. PV Industry Workshop on Thin Films, Ispra, 2007

SOLYNDRA
High Performance Photovoltaics

CIGS-Based Thin-Film PV

Markus E. Beck
11-22-2007

Solyndra Introduction

- Location: Fremont, California, USA
- Technology: CIGS
  - vacuum deposition: CIGS, Mo back contact, i-ZnO/Al:ZnO window
  - wet chemical CdS junction partner
  - monolithic cell interconnect
- Substrate: Glass; 1.1m width
- Non-standard cell form-factor and packaging
- System Design Approach to lower total installed cost and lower cost of photovoltaic electricity
- Market Target: low slope rooftops

Technology Co-Operations

- Recycling and Environmental Aspects (joined PV-CYCLE)
  - LCA
  - Process waste material reclamation
  - End-of-use module collection & recycling
- Raw Material Sourcing Aspects
  - Evaporation feedstock supply chain and purity (Cu, In, Ga, Se)
  - Sputter target supply and quality; rotary targets (Mo, i-ZnO, Al:ZnO)
  - Glass substrate supply, potentially Mo-coated glass
- Cd-free buffer
- TCO optimization
- IEC standards (member of IEC TC82)
  - Performance
  - Reliability
  - Safety
  - Reference cells
- Employee sourcing
  - develop university PV programs

AVANCIS
ADVANCED SOLAR POWER

3rd International Workshop on thin film PV

21st November 2007

Paul Mogensen

CIS Marketing & Production History

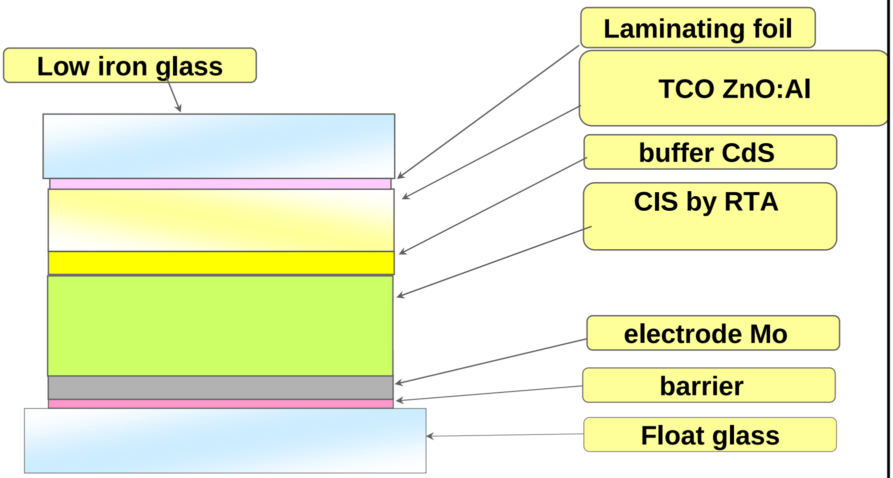
AVANCIS
ADVANCED SOLAR POWER

- **1981** Thin film development program initiated Arco Solar (a-Si. CIS, CdTe)
- **1993** CIS selected to continue in pilot plant
- **1998** 1st Generation commercial CIS production (10 W module)
- **2000** Introduction of 40W module
- **2003** 13.1% champion efficiency on 0.5m^2
- **2005** Introduction of 80 W_p CIS module
- **2006** AVANCIS Joint venture formed for 2nd Generation CIS production
- **2007** Construction of 2nd Generation production facility
- **2008** Planned start of production of 120 W_p CIS module

Shell PowerMax ECLIPSE

AVANCIS TECHNOLOGY

AVANCIS
ADVANCED SOLAR POWER



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AVANCIS TECHNOLOGY

AVANCIS
ADVANCED SOLAR POWER

Avancis aims to have

- High Quality
- High Performance products comparable to Si
- High Stability long lifetime products (tests modules have withstood 4000h DH)

And to be competitive with Si based modules

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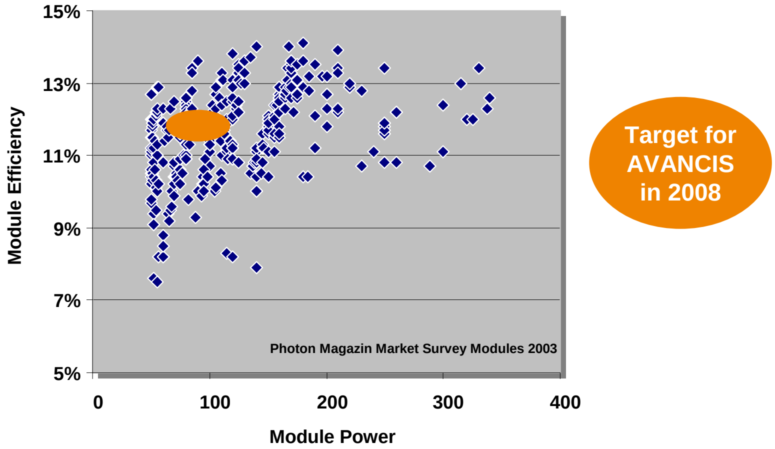
MARKET POSITIONING

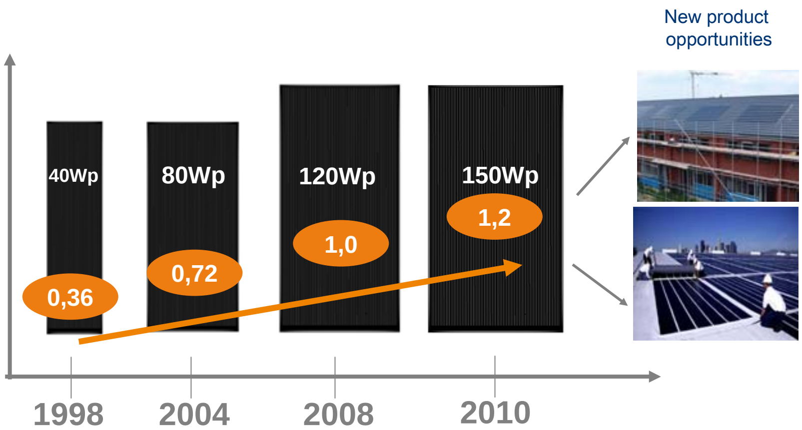
AVANCIS
ADVANCED SOLAR POWER



AVANCIS Module Efficiency will be in Ballpark Range of Poly Si Modules

AVANCIS product Roadmap

AVANCIS
ADVANCED SOLAR POWER



AVANCIS product sizing

AVANCIS
ADVANCED SOLAR POWER

3210mm

6000 mm

Based on Standard European float glass size

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AVANCIS product sizing

AVANCIS
ADVANCED SOLAR POWER

3210mm

Sputtered Molybdenum coating

6000 mm

Avancis pre-product is coated on standard glass coater and then cut to size

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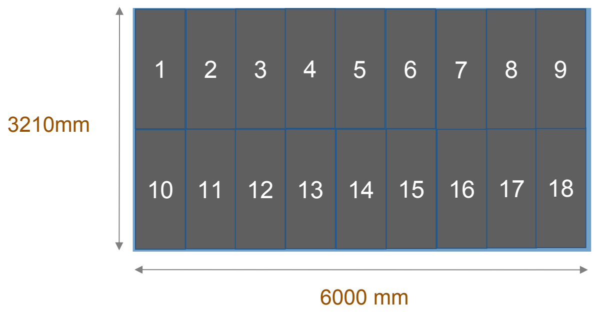
AVANCIS product sizing

AVANCIS
ADVANCED SOLAR POWER



18 substrates cut from a standard Jumbo glass size with an optimised yield of 98%

AVANCIS product sizing

AVANCIS
ADVANCED SOLAR POWER

- **Product will be competitive with wafer based Si modules and to be suitable for large arrays.**
- **Aim to move towards larger substrate sizes**
  - fewer pieces from a Jumbo Format ?
- **Long term idea would be to keep substrate size as large as possible as far as possible in the module process.**
  - We therefore require appropriate production ad measurement equipment

AVANCIS supports Equipment standardisation

AVANCIS
ADVANCED SOLAR POWER

Standard Product Size *Module size, mother sbstrate size*	Standard Process Steps *PVD-CIG, PVD-ZnO, Patterning, Assembly*	Standard Platforms *Sub-line concepts*
Enables standard size for chambers and std automation design	Enables robust process developments and CoO optimization	Enables mature design for cost and reliability
Lower equipment cost	Lower CoO and less process develop. cost	Lower equipment cost
Product size roadmaps	Technology roadmaps	Equipment roadmaps

Compelling evidence from FPD Industry: Standardization of thin film processes and equipments allows significant cost reductions and more effective R&D programs.

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AVANCIS-Facilities

AVANCIS
ADVANCED SOLAR POWER

1st Production facility in Torgau - on glass industry site

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STATUS

AVANCIS
ADVANCED SOLAR POWER

- **Facilities completed**
- **Equipment move in starting**
- **Production planned for Mid 2008**
- **Recruitment of key personnel completed**
  - 100 employees by end of 2008

- **Planning started for additional 80MW capacity on Torgau site**

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Manufacturing $CuInS_2$ solar modules
Sulfurcell Solartechnik GmbH, Berlin

A. Neisser

Sulfurcell Solartechnik GmbH
Barbara-McClintock-Str. 11, D-12489 Berlin, Germany

neisser@sulfurcell.de, Phone: +49-30-63923823, Fax: +49-30-63923800

Sulfurcell - More than 5 years of experience in $CuInS_2$ technology

Snapshot
- Based on new technology from Europe's largest research institute for thin-film PV (HMI Berlin)
- Erected in 2003
- Currently employing 100 people (12 specialists, 80 operators, technical/administrational staff)

Objectives of the pilot production
- ✓ Scale-up from 5 cm x 5 cm to 125 cm x 65 cm
- ✓ Prove feasibility of manufacturing
- ✓ Develop 50 MW capable processes
- ✓ Check out market perception

Now: Learning by manufacturing

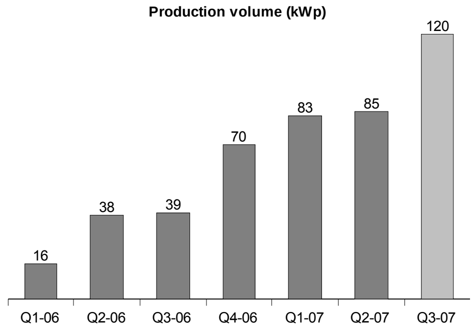
Sulfurcell developed its technology in an industrial environment in order to optimise processes for mass production

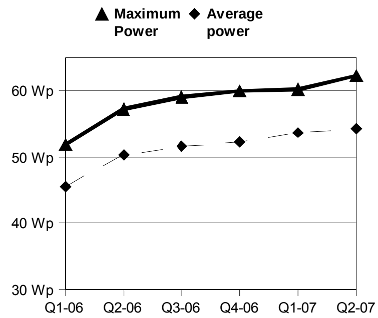
Steady increase of production output
Continuous improvement of best and average module efficieny

Key figures of Sulfurcell production

Cummulative power reaches ≈ 0.5 MW end of Q3-07

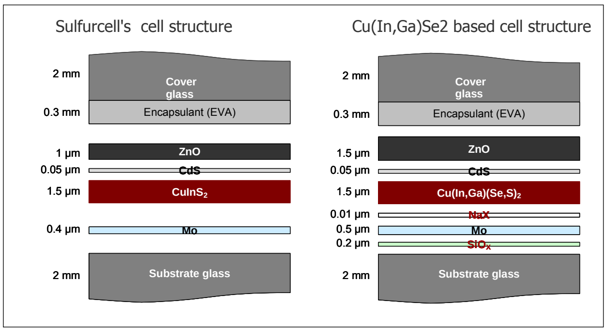
Continuous 7-days operation will start in Q4 --> run rate of 2 MW in Q1/08





SULFURCELL

Introduction – Technology



A simplified cell structure enhances process stability and robustness

Sulfurcells production technology

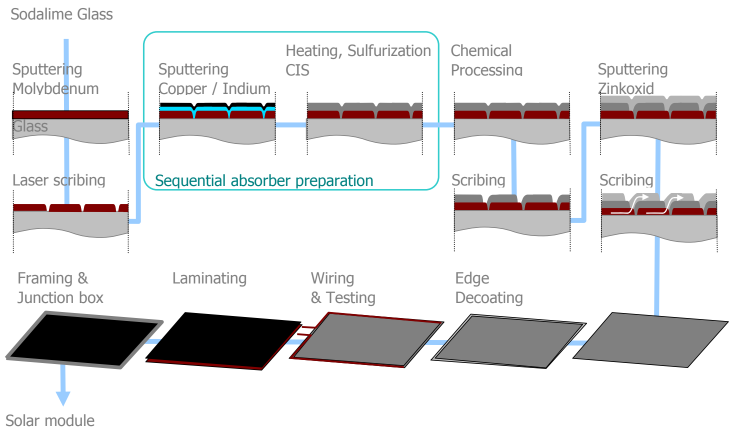
- Architectural glass coating techniques
- Sputtering techniques for all thickness defining process steps
- Sputtering allows low capital expen-ditures for large production capacities

- A high level of stability inherent in the production process is due to:
  - Simple cell structure
  - Sequential preparation of the compound CIS
- High productivity is driven by:
  - Use of highly reactive Sulfur instead of Se
  - Rapid thermal processing
  - Absorber formation in less than 5 minutes
- Cost saving materials

SULFURCELL

3rd International Workshop on Thin Films in PV Industry, Ispra, Italy

Introduction – Production process



A lean production process involving five deposition steps

SULFURCELL

3rd International Workshop on Thin Films in PV Industry, Ispra, Italy

Gap between lab and production further reduced

Comparison of small area and module efficiency

Type	**Cell**			**Module**		
Manufacture	**Lab (HMI)**	**Prod. (SC)**		**Lab (HMI)**	**Prod. (SC)**	
Area [sqcm]	**0.5**			**5 x 5**	**121 x 61**	
Status	**certified [1]**	**06.06**	**07.07**	**certified [2]**	**06.06**	**07.07**
Eff [%]	**11,4**	**9,2**	**10,4**	**9,7**	**7,6**	**8,6**
Voc [mV/cell]	**729**	**680**	**698**	**723**	**601**	**659**
FF [%]	**71,7**	**69,5**	**70,9**	**66,6**	**67,2**	**66,8**
Jsc [mA/cm^2]	**21,8**	**19,4**	**20,9**	**20,1**	**19,5**	**19,5**

[1] K. Siemer, J. Klaer, I. Luck, J. Bruns, R. Klenk, D. Bräunig, Solar Energy Materials and Solar Cells, 67 (2001) 159-166.
[2] J. Klaer, I. Luck, A. Boden, R. Klenk, I. G. Perez, R. Scheer, Thin Solid Films 431-432 (2003) 534-537

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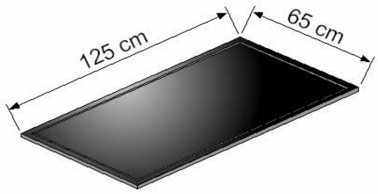
Substrate size - scale-up 2003-2004

Scale-up 5 x 5 cm² → 125 x 65 cm²

Hahn-Meitner-Institute



Sulfurcell

The scale-up was successfully completed in 2004

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Page 7

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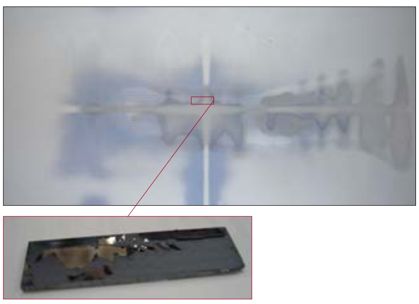
Introduction – Scale-up 2003-2004: Challenges

Pictures of 125 cm x 65 cm sized CIS layers after sulfurisation

Initial process



Advanced process

Process: Rapid thermal processing of copper/indium layers under sulfur vapor (top-temperature: 500 °C)

Key scale-up challenge: Homogeneous, adhesive CIS

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Page 8

Substrate size – some remarks

Market – customer feed back

Roof installation
- require for rather flexible montage zones - there is no standard roof yet
- Substrate size is limited by what a single workman can handle wrt. size and weight ($1m^2$, 30kg)

BPIV - Fassade integration
- 2,5m seems to be common unique length for elements - BIPV products should be multiples of this

Large installation / power plants
- high acceptance of $1m^2$ format
- (highly automated installation might ask for large module sizes)

Manufacturing of large area substrates

Processing / handling
- 6 x 3 m^2 glass substrates are common practice in glass industry

Layer deposition
- Sputtering technology: is available
- Patterning: should not be a problem, although precise position of substrate and laser ±5µm challenging
- **Rapid thermal processing: lateral homogeneous fast temperature and pressure ramps at area >$1m^2$ still challenging, will require more R&D efforts**

Module finishing
- no problem

Sulfurcell sees a high acceptance of its current substrate size of 125 x 65 cm^2 at the market

SULFURCELL

Marketing strategy – Focus on individual solutions such as BIPV

Roof top system

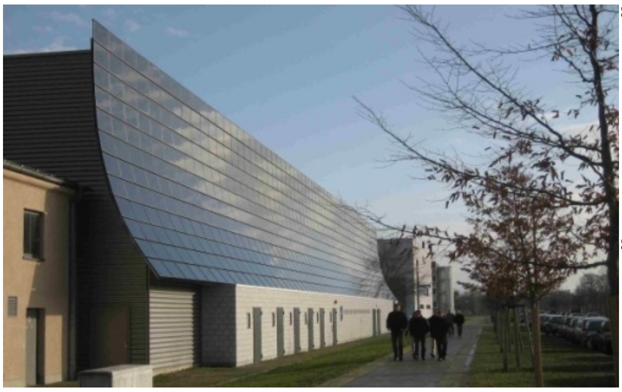
Private house in France applying Sulfurcell's RI modules

Conventional roof-top systems

Thin films offers excellent solutions for solar architecture

SULFURCELL

Sulfurcell's approach in BIPV



PV fassade at the Ferdinand Braun Institut Berlin

Sulfurcell's guidelines in developing new products for solar architectuce

- Solar modules should fit high aesthetic expectation in order to be attractive as building material
- Prices per square meter should not be higher than those of passive premium materials
- Installation of modules and installation system must be easy and standardised

Sulfurcell's products for BIPV

- Homogeneous, black
- High aesthetics at reasonable price
- Specialized frames

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3rd International Workshop on Thin Films in PV Industry, Ispra, Italy

Substrate size – Jumbo Module

The Jumbo Module

- Sulfurcell has designed a 3m^2 demonstrator for a 200W module suited for roof and fassade integration (in cooperation with partner)
- Compatible in size with thermal solar collector
- Large size laminate of 3½ standard PV modules
- presented at the PV conference in Dresden in Sept. 06

Summary

- Targets of pilot production – scale-up, feasibility, product development – fullfilled
- Targets in pilot line 2008
  - Drive continuous KPI improvement before next ramp-up step
  - Build-up knowledge about relevant technological and manufacturing issues ("make errors now, not later")
- High acceptance of 125 x 65 cm2 module size at the market
- Next step
  - Planning phase of ramp up to 50MW has already started
  - Product size will be same as in pilot

SULFURCELL

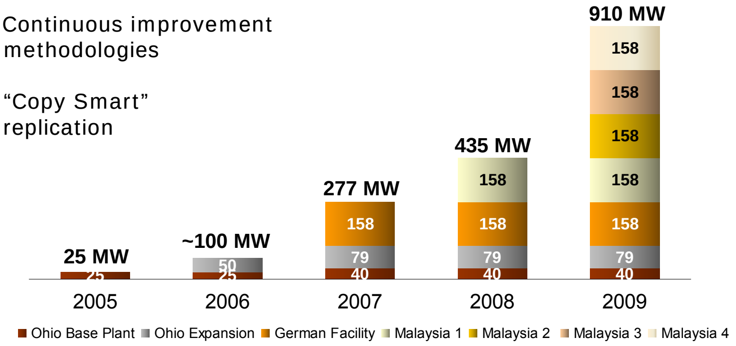
First Solar Company Overview

November 2007

Dave Eaglesham

Manufacturing ramp

- Proven replication at Base Plant
- Continuous improvement methodologies
- "Copy Smart" replication



Company Overview

First Solar.

910MW of Capacity in Operation or Under Construction [1]

Perrysburg, Ohio

- Scaled first module production line in the U.S. to steady state volume in 2005, added two production lines in 2006

Frankfurt (Oder), Germany

- Four production lines (158MW) constructed in Frankfurt (Oder), Germany which reached full production during second half of 2007

Kedah, Malaysia (under construction)

- Four, four-line plants (158 MW each) are under construction with full production targeted by second half of 2009
  - Plant 1 will reach full production during second half of 2008
  - Plant 2 & 3 will reach full production during the first half of 2009
  - Plant 4 will reach full production in second half of 2009

In November 2007 we increased the nameplate capacity from 30MW to 39.6MW per line

Based on Q3'07 run rate

MD-5-921 US November 2007 3

Thin-film PV Industry Development in Greece

C Protogeropoulos

Solar Cells Hellas Group

EU–JRC
3rd Int. PV Industry Thin-film Workshop, JRC/IES 22–23.11.2007

Solar Cells Hellas Group of Companies

1. **Production of Wafers, Solar Cells and PV Modules**

   Solar Cells Hellas, SolTech and Energy Solutions

2. **Design, Trading of Components and Construction of PV Systems**

   RENI – Renewable Energy Innovations

3. **Development of PV Stations**

   Solar Datum, 4E Energy, Solar Concept, Spes Solaris etc.

SOLAR CELLS HELLAS GROUP

EU–JRC

Solar Cells Hellas SA – General

- Company founded in 2005.
- Factory now under development in the industrial zone of Patras.
- Production of crystalline silicon wafers, cells and modules.
- Final annual capacity 60MW.
- First 30MW production: December 2007.
- Full capacity: mid 2008.

- Facilities: buildings 14.000m^2, land 37.000m^2.
- Working Positions: 230
- Member of EPIA.
- www.schellas.gr

3

SOLAR CELLS HELLAS GROUP

EU–JRC

3rd Int. PV Industry Thin-film Workshop, JRC/IES 22–23.11.2007

Solar Cells Hellas SA – Patras Factory

September 2006

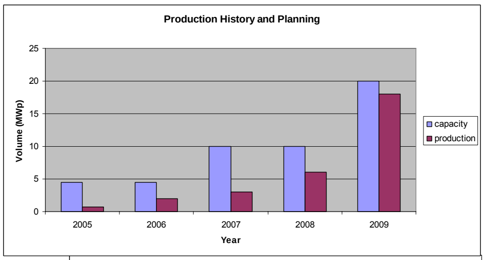
June 2007

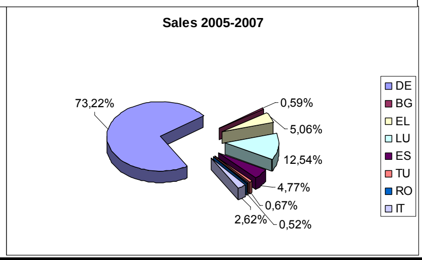
February 2007

Energy Solutions SA – General

Energy Solutions

- Company founded in December 2003.
- Located at Pernik industrial complex, 30km SW of Sofia, Bulgaria.
- Working Positions: 21 people.
- Member of EPIA.
- www.energysolutions.gr





SOLAR CELLS HELLAS GROUP
EU–JRC
3rd Int. PV Industry Thin-film Workshop, JRC/IES 22–23.11.2007

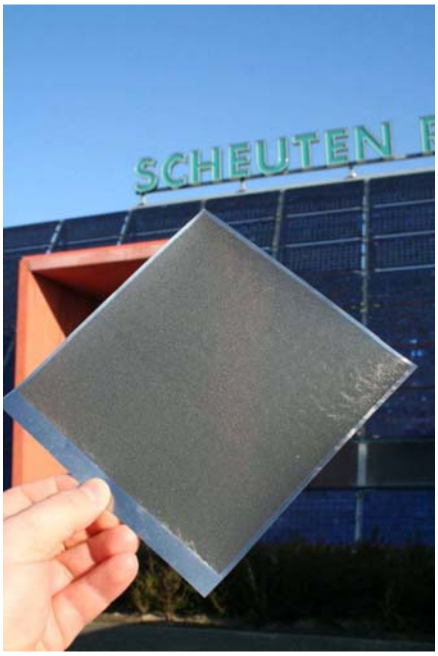
Thin Film Fabrication Hellas SA

- Development of new facility for thin-film production in the Industrial Area of Patras.
- Building area 15,000m^2, land 47,000m^2.
- Tandem thin-film technology: a–Si(0.3μm)/μc–Si(1.5μm).
- Module dimensions: 1.3m×1.1m (area 1.43m^2).
- Module nominal power and efficiency: 120Wp, η=8.4%.
- Envisaged annual production capacity: 30MW (250,000 modules)
- Collaboration with Oerlikon.
- Investment description and business plan submitted last month in the Development Law 3299/2004 for subsidisation.

6

solar | glass Scheuten

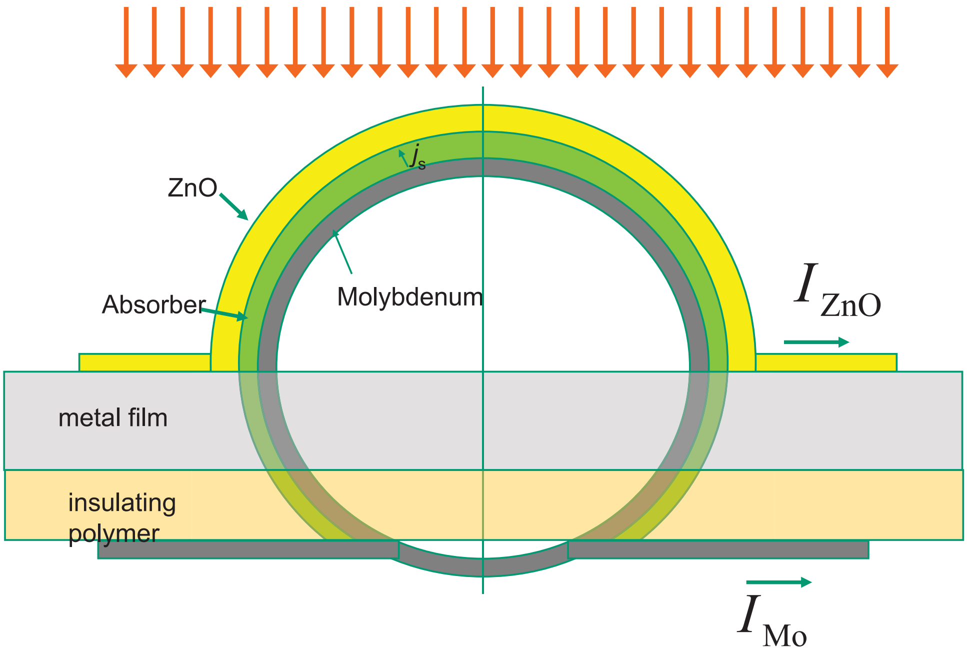
Sunrise solar cells



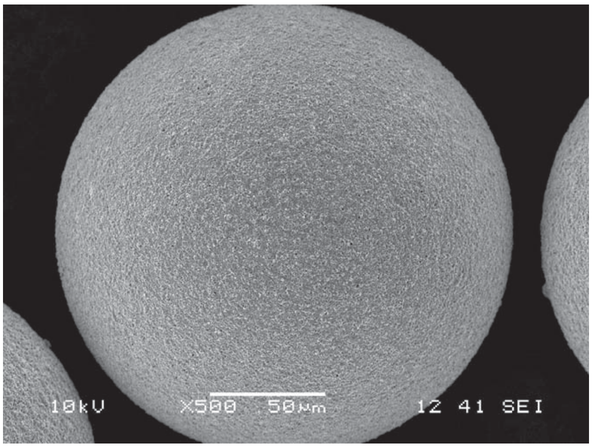
22 november 2007

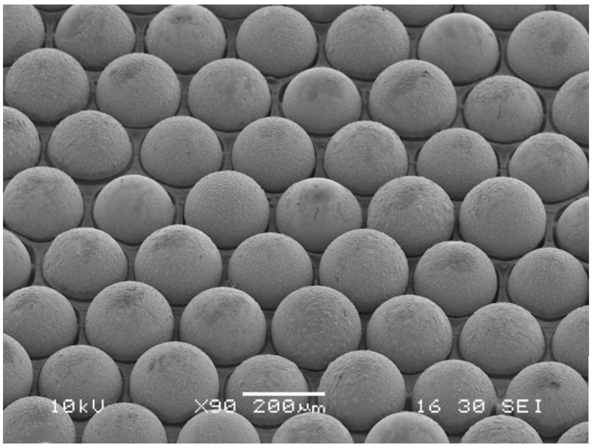
solar | glass Scheuten

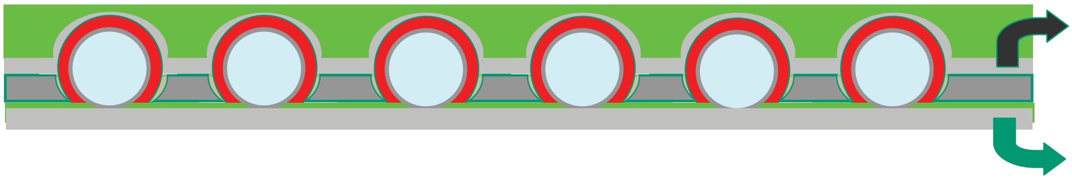
Side view of cell



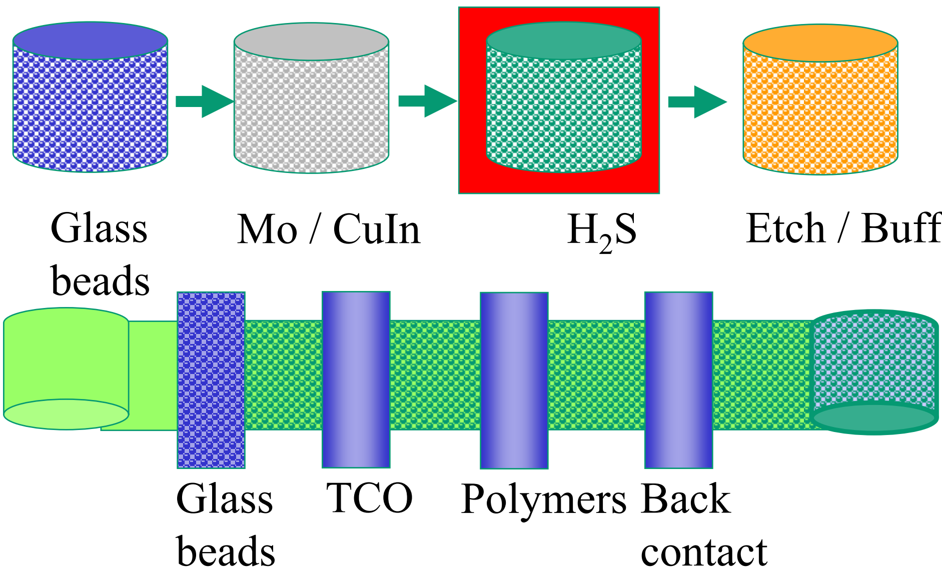
22 november 2007







Proces steps



solar | glass Scheuten

22 november 2007

Helianthos solar cell laminates

Solar cells generating
clean affordable electricity
for nowadays societies

Gert Jan Jongerden

NUON

Outline

- **Introduction**
- Helianthos roll-to-roll solar cell laminate manufacturing
- Pilot line
- Flexible tandem PV laminates
- Up scaling

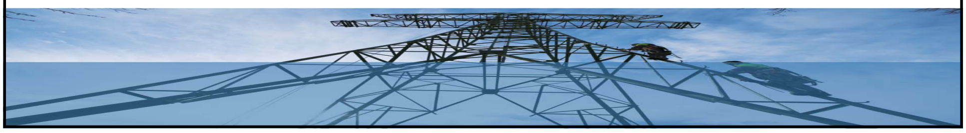
NUON

2

Nuon, a leading energy company

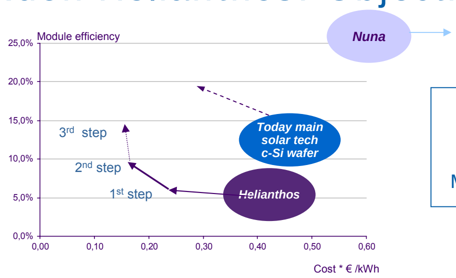
Nuon is active in the generation, marketing, sale and transportation of (renewable) energy.

- Vertically integrated Dutch utility company
- Private company owned by provinces & municipalities
- Founded in 1998 from merger of regional Dutch utility companies
- Net turnover of ~ €5.6 bln,
- Total assets of ~ €10.8Bn; 9.700 employees
- 3.500 Mw power generation capacity
- Innovative company with sustainable business and financial profile ; frontrunner in Renewable Energy (2006, 0.6 TWh)
- Core countries: The Netherlands, Germany & Belgium



Winner of world solar challenge 2001, 2003, 2005 **& 2007!**

Nuon Helianthos: Objective



kWh costs ↓

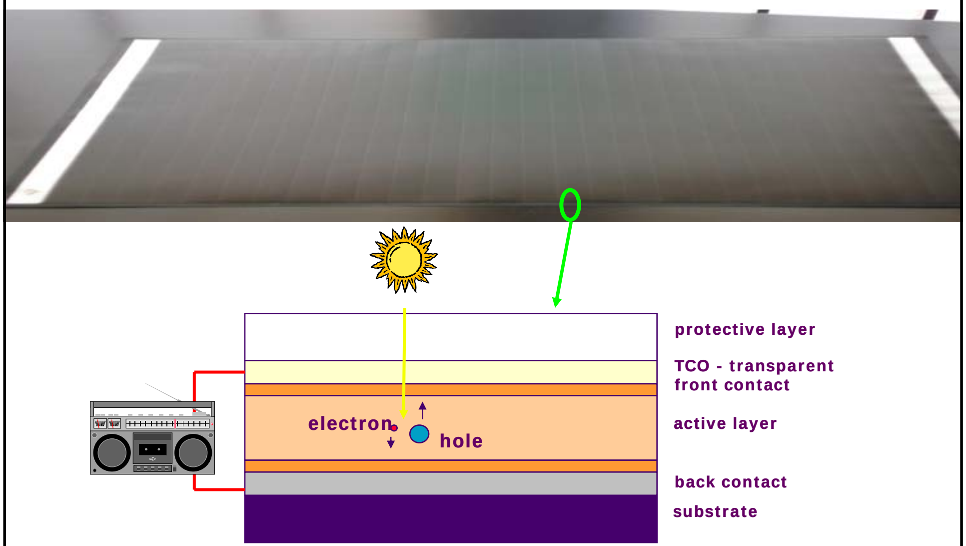
↓

Module costs ↓ + System integration costs ↓

Solar cell laminate products:

- Roll-to-Roll production technology
- Flexible & lightweight modules
- Si technology: abundant + eco-efficient

Structure solar cell laminate



From pilot line to large scale production

Feasibility study lab cells

Industrial piloting:
- **Roll-to-Roll Pilot Line**
- **Test marketing**

Large scale production

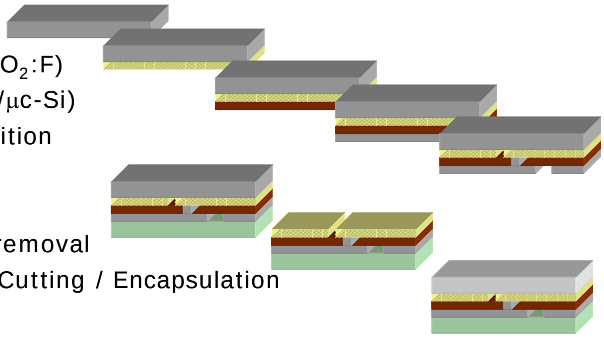
1997-2000	2001 – 2008	2009 - …
	R2R pilot	1 km²/yr unit (~ 75 MWp) gradual build up
	Starting development with 'integrators', e.g building (element) parties	PV laminates for 'building integrated PV'

Roll-to-Roll Pilot Line

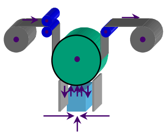
- 35 cm wide foil
- *a*-Si:H p-i-n single junction
- monolithic series integration
- Objective:
  - Test industrial feasibility
  - Process R & D
  - Market development

Temporary 'superstrate': schematic processing sequence

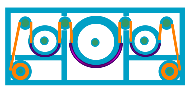
- Al foil
- TCO deposition (SnO_2:F)
- a-Si:H deposition (/µc-Si)
- Back contact deposition
- Patterning
- Carrier lamination
- Temporary carrier removal
- Connection point / Cutting / Encapsulation
- [QC]



Helianthos process sequence

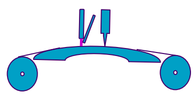


TCO deposition: APCVD

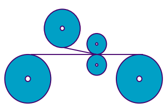


Si deposition: PECVD

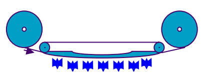
Back contact: sputtering



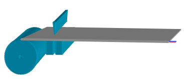
Series connection



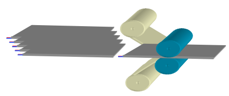
Lamination of carrier foil



Etching of temporary foil

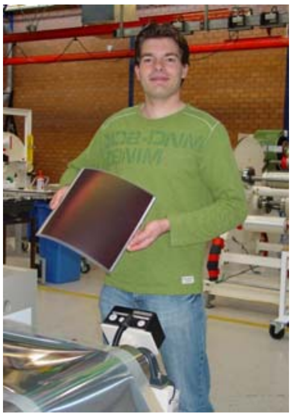


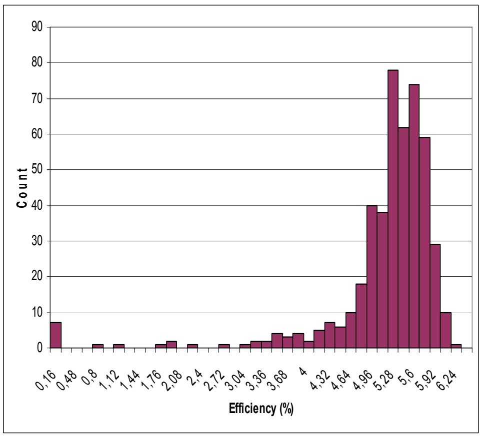
Contacting and cutting



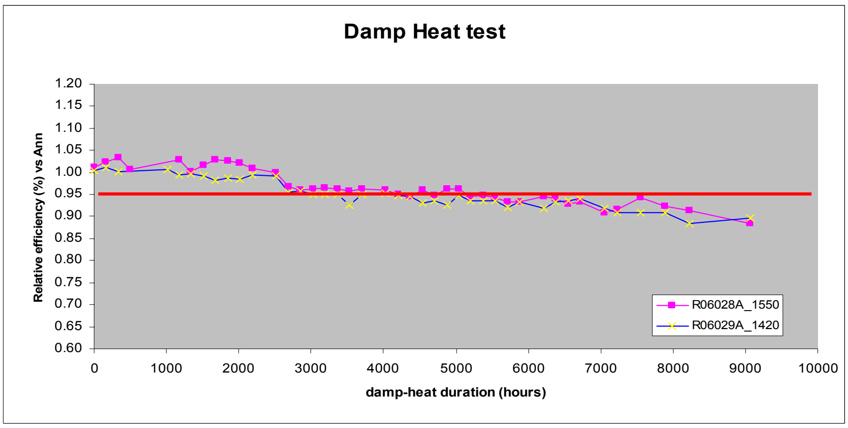
Encapsulation of modules

Efficiency pilot line PV laminates (apert. area stab.)

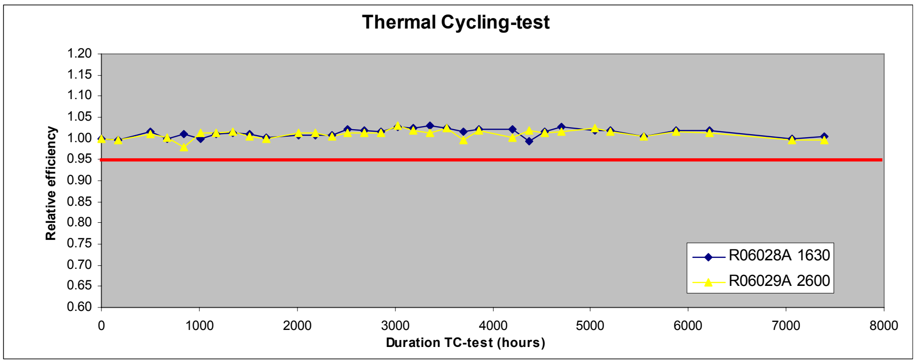




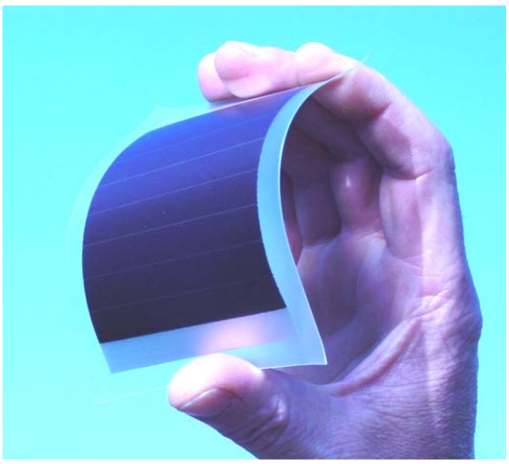
Damp Heat



Thermal cycling



Tandem modules



Nuon Helianthos

Know How Partners

Utrecht University

FZ Jülich (IPV)

Delft University of Technology

Eindhoven University of Technology

Netherlands Organization for Applied Scientific Research

Energie Centrum Nederland

Efficiency ↑

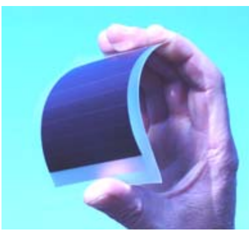
+

deposition time ↓

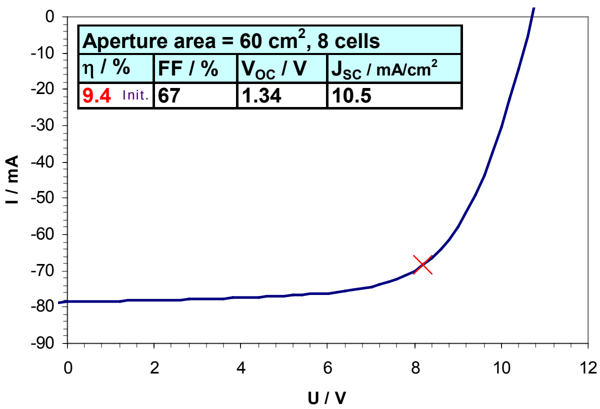
15

Nuon Helianthos

a-Si/µc-Si tandem module: increasing efficiency in lab line with know how partners



- Stabilized eff. 8%



16

Large area modules

1 X 0.3 m^2

Init. efficiency 6 %

Larger area modules

6 X 0.3 m^2

Init. efficiency ~6%

Up scaling

- Substrate size
  From 0.3 m (pilot) to 1 – 1.5 m wide (production)
  Roll length 1 km (pilot) to 3 – 5 km (production)
- Annual capacity
  From 0,001 – 0,01 km^2/yr (pilot) to 1 – 10 km^2/yr (production)
- Efficiency
  Single a-Si (6 - 7% a.a.s.) - tandem a-Si/nc-Si (9 - 11 %) - third gen (15 – 20 %)
- High throughput active layer deposition incl. efficient duty cycle
- Abundant, eco-efficient materials
- Improved materials functionality and utilization
  e.g. foils, resins

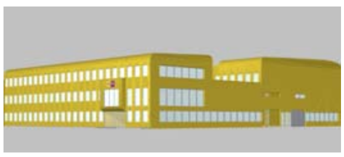
From roll-to-roll process to electricity production on the skin of buildings

innovative pilot line process | **solar cell laminate (semi-finished product)** | **Integrated solar cell - roofing element** | **solar electricity producing building**

In the Netherlands 70 m² a-Si laminate produces the electricity for average household (3500 kWh /yr

Conclusions

- Development proceeding rapidly
  - Pilot line running for 30 cm wide a-Si solar cell laminates
  - Performance and reproducibility increasing
  - Larger modules produced (up to 6 meter long)
  - Field testing started
  - Up scaling starting
- New pilot facility – under construction



➢ Good progress towards affordable solar electricity

ALTIJD NUON

NUON

Manufacturing and Performance of CIS Modules
Large Volume Production of Würth Solar

WÜRTH SOLAR

Bernhard Dimmler
Würth Solar GmbH & Co. KG
Schwäbisch Hall
Germany
bernhard.dimmler@we-online.de

www.wuerth-solar.de

Outline: - company
- development of thin film PV
- Würth Solar: status and prospects
- products and performance

Wurth Solar
New production facility

WÜRTH SOLAR

CISfab
powered for the future

worldwide first CIS module Volume Production

1999 – 2006:
pilot production with 1.5 MW/a
Proof of concept
• CIS with high quality
• high productivity

2005/2006: 18 month from ground Breaking to full capacity running

2007: 15 MW running

Further scaling until spring 2008
Up to 30 MW/a

Wurth Solar
New production facility

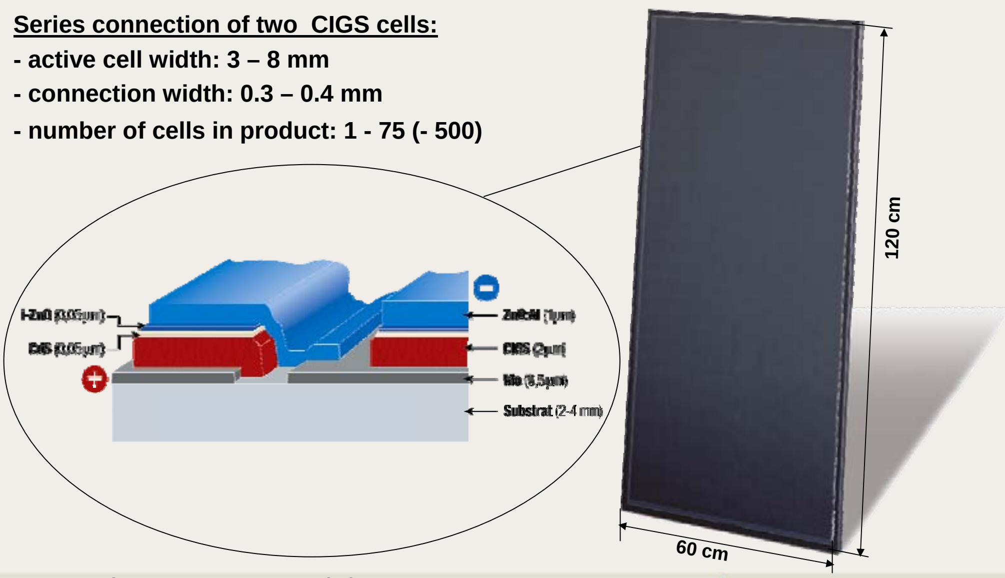
cisfab
powered for the future

- Capital investment: 55 million €
- Total facility area: 22.000 sqm. incl. administration and warehouse
- Annual output : 15 MW (200,000 CIS-Modules), 30 MW already included in planning
- Employees : 140 (as of 2007), continuous shift operation

3 Würth Solar / Bernhard Dimmler / PVSEC 22nd 2007 Milano

The CIS Thin Film Module

<u>Series connection of two CIGS cells:</u>
- active cell width: 3 – 8 mm
- connection width: 0.3 – 0.4 mm
- number of cells in product: 1 - 75 (- 500)



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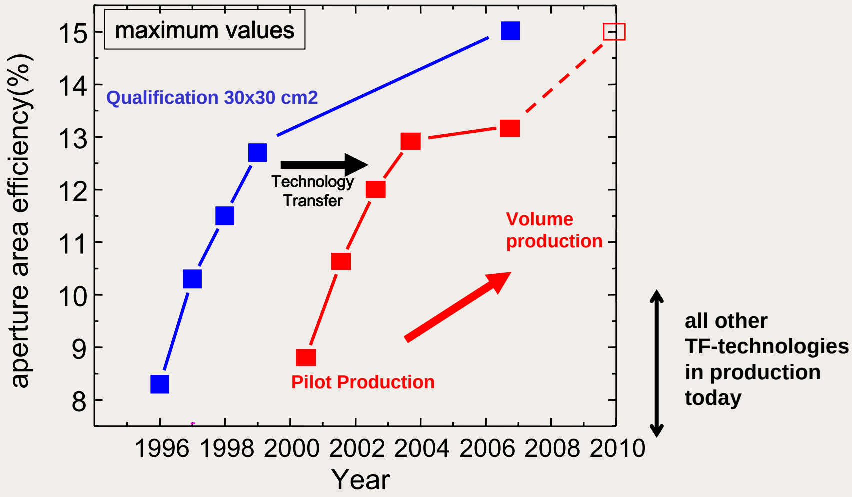
CIS Technology Roadmap

WÜRTH SOLAR

ZSW laboratory line: 30 x 30 cm²
Würth Solar production : 60 x 120 cm²



Improvements in Production Technological Roadmap

WÜRTH SOLAR

Product quality : average module efficiency: ⇨ **> 14 %**
by continuous process optimization, stabilization and innovations

Productivity: - improvement of overall process yield: ⇨ **> 90 %**
by continuous process optimization and improved process control

- reduction of cycle time, mainly CIS by technological improvements and innovations ⇨ **<<10min.**

- longer term: increasing product area in production

Materials: reduction amount of material (yield, thickness),
recycling of production waste,
longer term: new module concepts (foils)

EPIA-SEMI PV Standards Technical Committee

Daniel Fraile Montoro

SEMI-EPIA PV Standards Technical Committee, ISPRA 23th November 2007

Why a EPIA-SEMI PV Standards Technical Committee?

1. European procedures are too complicated to follow and too low (confusion and chaos)
2. No control from the Industry on what the standard institutions are developing
3. Unclear added value for the end-user
4. Develop only useful standards for the industry

SEMI-EPIA PV Standards Technical Committee, ISPRA 23th November 2007

Benefits of EPIA-SEMI PV Standards Technical Committee

1. SEMI Standards have an excellent development time when compared with other Standards Developing Organizations.

2. The Standards will be developed by the industry for the industry (volunteers assigned by their companies):

   > *Integration of the Industry inside the standardisation process will achieve the Development of the 'right' standards*

3. Global Scope

4. Easy Participation (most communication is electronic with increased usage of teleconference and web-based applications)

Benefits for the Industry

New or improved standards will contribute to:

- Reduce costs in design, production and deployment
- Foster fair and transparent competition

EPIA-SEMI PV Standards Technical Committee

- **Aim:** Implementation of new standards (Quality &Performance) and update of the existing ones.
- **Scope:** Cover the whole value chain from feedstock to BOS

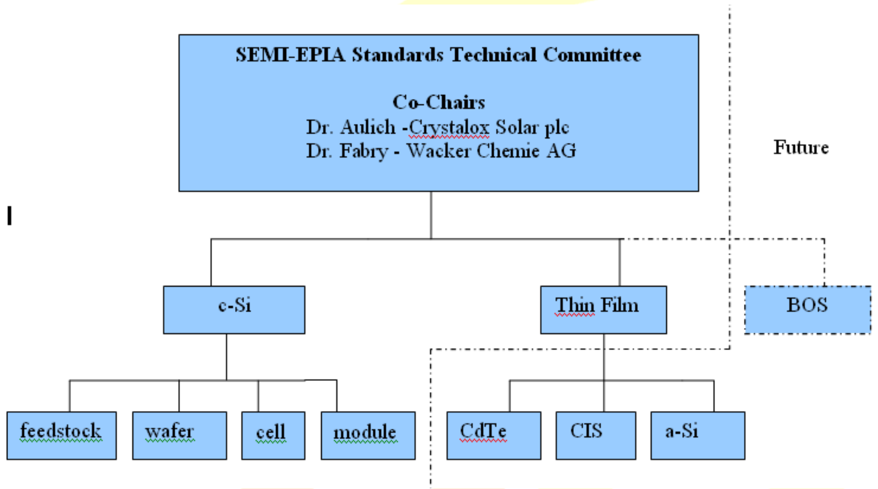
- **Co-Chairs:**
  - •Dr. Hubert Aulich (Crystalox Solar)
  - •Dr. Laszlo Fabry (Wacker chemie)

- **Current Activities:**
  - •Defining the Structure of the Committee (by products, by markets, by specific request from the Industry, etc.)
  - •Gathering the industry needs (questionnaires)
  - •Creating the first Taskforces

SEMI-EPIA PV Standards Technical Committee, ISPRA 23th November 2007

Possible Structure by Products

I



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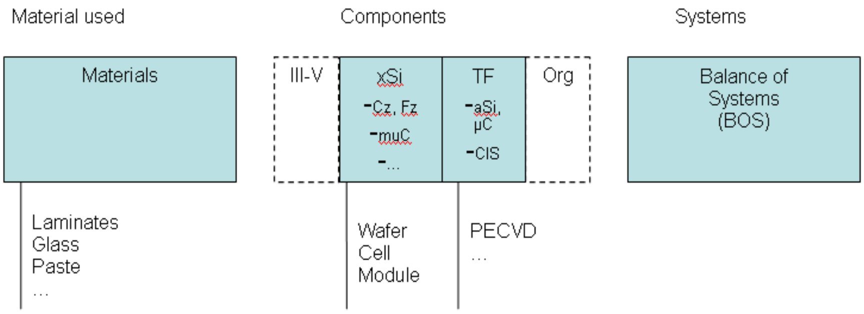
Possible structure by Markets



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First Task Force on EIS (Equipment Interface Specifications)

1. Creation of the Task Force and nomination of the leadership (Milan, 7th September 2008)
2. Definition of structure, working group and participant (Stuttgart, 10th October)
3. Expected publication of the Standards (October 2008)

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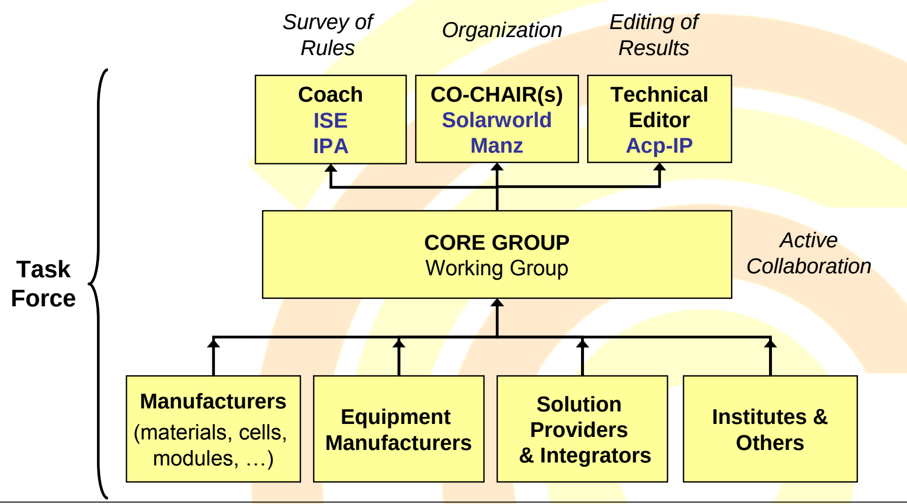
PV-EIS Task Force - Structure



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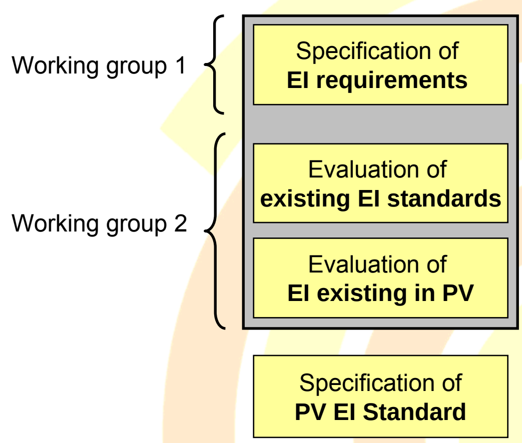
Working Group: Scope and structure



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Work Group 1 – Sign Up / Lead

Task: "Specification of EI requirements"
Lead: M. Boltz, acp-IT

Equipment Manufacturers:
- Oerlikon
- Manz

Manufacturers **(material, cells, modules):**
- Ersol
- DC
- Conergy
- Q-Cells

Solution Providers / Integrators:
- AIS
- Camline
- acp-IT
- Cimetrix

Institutes and Others:
- IPA
- ISE

SEMI-EPIA PV Standards Technical Committee, ISPRA 23th November 2007

Work Group 2 – Sign Up / Lead

Task: "Evaluation of existing interfaces and standards"
Lead: M. Glaser, Manz

Equipment Manufacturers:
- Centrotherm
- Manz
- Rofin SINAR
- R&R

Manufacturers (material, cells, modules)

Solution Providers / Integrators:
- Siemens
- acp-IT
- AIS
- Cimetrix

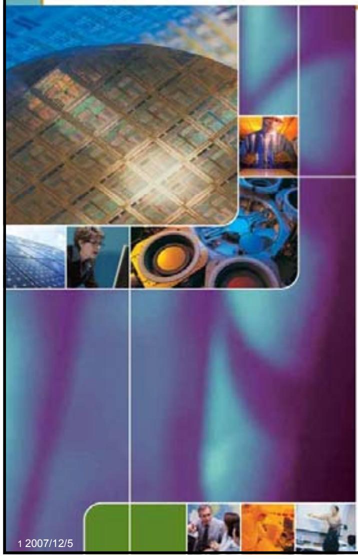
Institutes and Others:

SEMI-EPIA PV Standards Technical Committee, ISPRA 23th November 2007

Thanks for your attention

All of you are welcomed to participate in the SEMI-EPIA program for PV standards

3rd International Workshop
Thin Films in the Photovoltiacs Industry Nov 2007



How can a new and emerging technology
as Thin Film PV
profit from Standardization?

Werner Bergholz

1 2007/12/5

Outline

- ***What is standardization?***
- ***What is the benefit?***
- ***How?***

2 2007/12/5

What is standardization ?

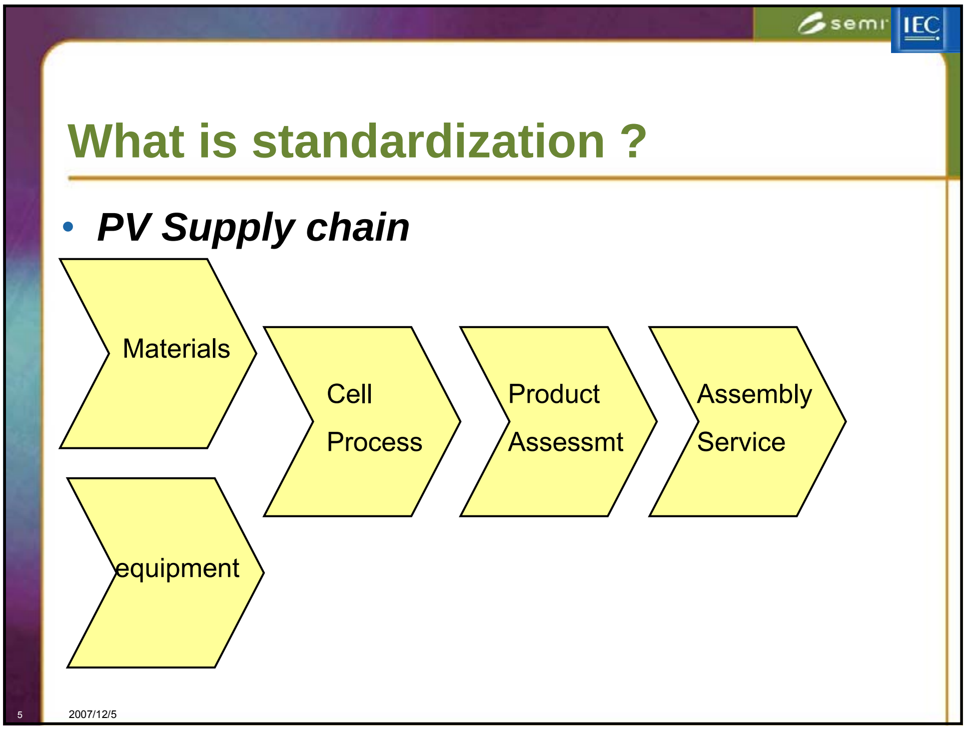
- *What it is not: Static → block progress*
- *A standard is a „living“ dynamic document*
  - *Regular reviews*
  - *At the latest after 5 years*
  - *Takes into account technical progress*
  - *Enables improvement*
  - *Enables elimination of mistakes*

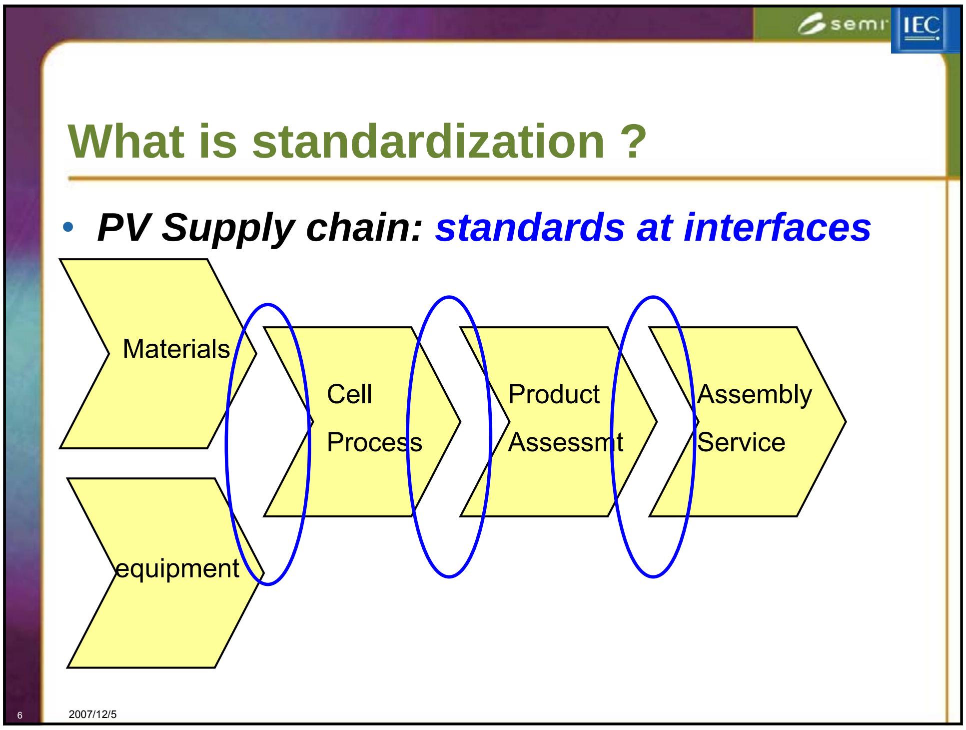
3 2007/12/5

What is standardization ?

- *Examples for standards:*
  - *A4 paper, USB computer accessories*
  - *generic purchasing specification(s) for equipment or materials*
  - *A standardized characterization method*
  - *A standardized equipment or PV cell assessment*
- *What kind of systematics can we find for standardization?*
- *Common factor: an element of the supply chain*

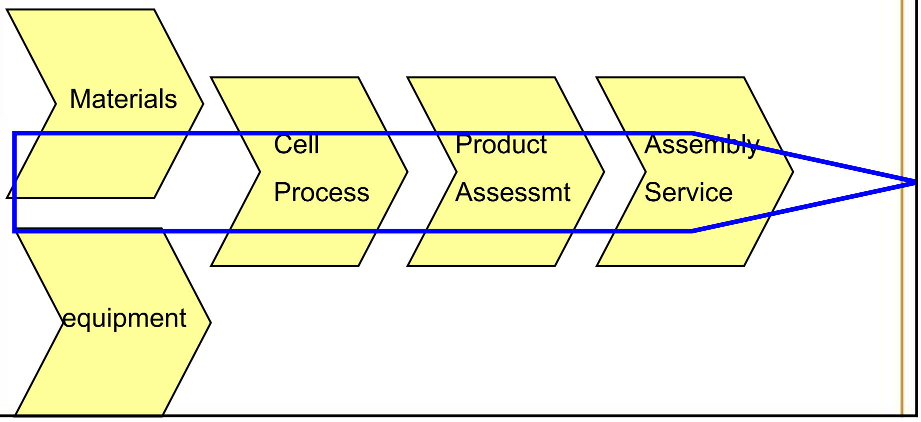
4 2007/12/5


What is standardization ?
• PV Supply chain
Materials
equipment
Cell
Process
Product
Assessmt
Assembly
Service
5
2007/12/5


What is standardization ?
• PV Supply chain: standards at interfaces
Materials
equipment
Cell
Process
Product
Assessmt
Assembly
Service
6
2007/12/5

What is standardization ?

- ***PV Supply chain: standards along the complete value chain***



7

What is standardization ?

- ***Examples: Assessment***
  - ***Standard for measurement of material parameters***
  - ***Standard for assessement of uptime, productivity, safety of equipment***
  - ***Standard for assessement of certain product properties, such as efficiency, durability, reliability***
  - ***....***

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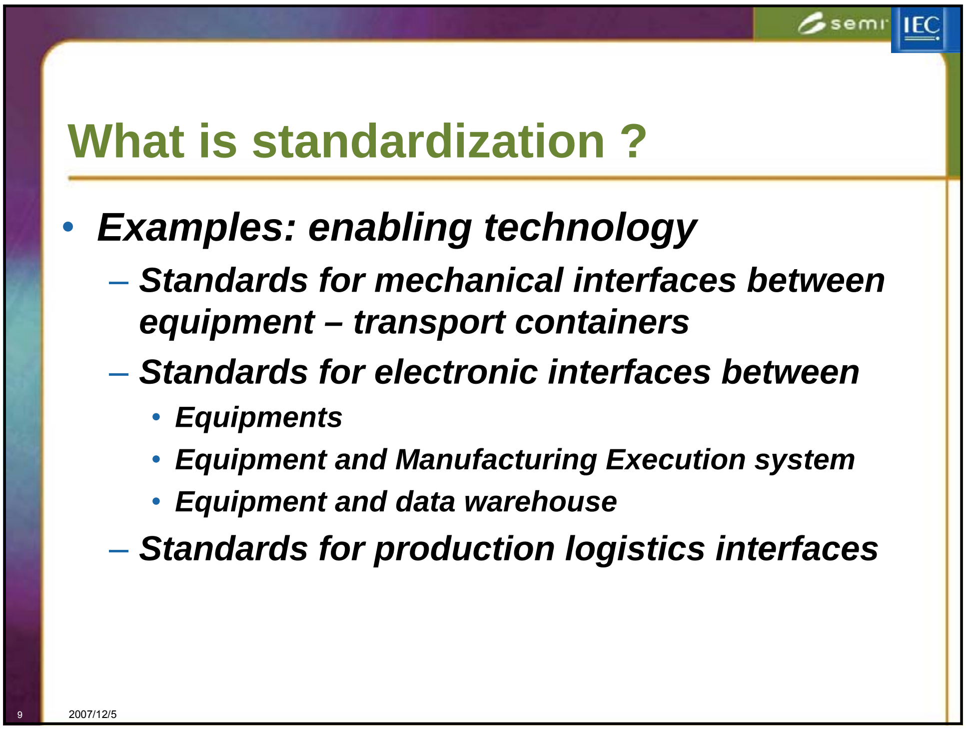
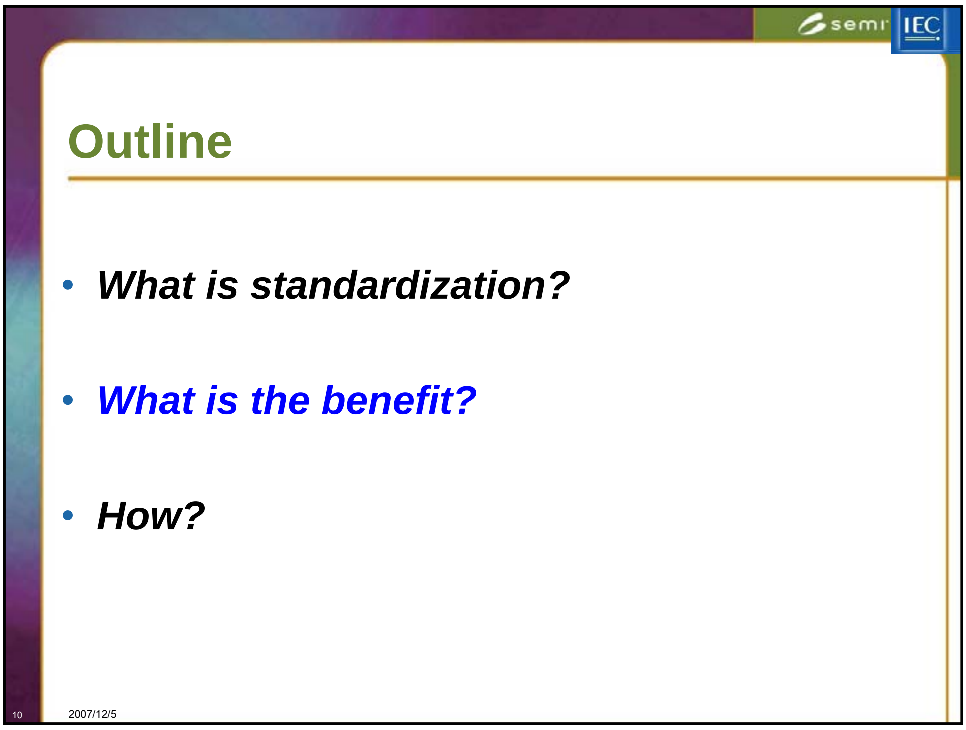

What is standardization ?
• Examples: enabling technology
– Standards for mechanical interfaces between equipment – transport containers
– Standards for electronic interfaces between
• Equipments
• Equipment and Manufacturing Execution system
• Equipment and data warehouse
– Standards for production logistics interfaces
9
2007/12/5


Outline
• What is standardization?
• What is the benefit?
• How?
10
2007/12/5

Benefits

- *DIN study: general advantages*
  - *Multiple sources decrease cost and increase security of supply*
  - *Standardization lowers the entry barrier for competition*
  - *VW: standardized components: 40 – 60% cost reduction*
  - *Airbus: factor of 15 reduction of cost for standardized components, A320: 18 million savings in reduction of storage costs*

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Benefits

- *SEMI examples*
  - *1973: Si wafer shortage*
    - *due to „inflation" of Si wafer specifications*
    - *First SEMI M1 standard quickly adopted by 80%*
    - *higher productivity → enough Si wafers*
  - *1990s: EHS standard S2*
    - *Reduction of start up time for each tool: 2 weeks*
    - *Total cost savings: 6 Million $ = 1% of total cost*

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Benefits

- ***SEMI examples***
  - ***SEMI GEM SECS software standard***
    - ***Interface between equipment and MES system***
    - ***Before: „Tower of Bable“***
    - ***After: plug and play***

→reduction of IT cost for host site software by

80%

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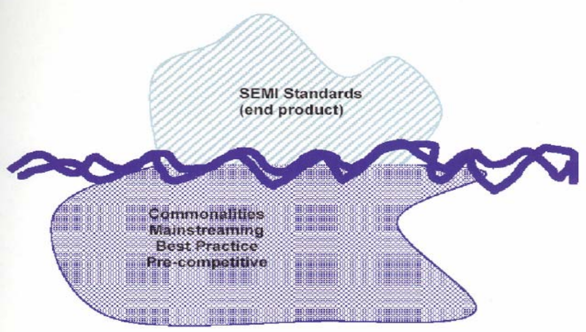
Benefits

- ***More „knowledge-management“ Benefits***



NOTE The "visible" benefit for procurement purposes is smaller than the hidden benefits through applications of standards in the area of knowledge management.

Figure 6 – Iceberg model of the perceived benefits of standards.

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Outline

- ***What is standardization?***
- ***What is the benefit?***
- ***How?***

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How

Standard Development Organisations

- **SEMI: Semiconductor Equipment and Materials International**
  - ***Industry Association of Microelectonics and FPD suppliers***
  - ***> 750 standards for***
    - ***Wafers, chemical, gases, other materials***
    - ***Equipment assessment stds (uptime, EHS,...)***
    - ***Mechanical and software interface standards***
  - ***Worldwide standards (North America, Europe, Japan, Korea, Taiwan, China, Russia)***
  - ***Consensus process: votes by companies***
  - ***Cycle time: 12 – 18 months***

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How

- **IEC (International Electrotechnical Commission)**
  - ***National standardisation bodies contribute, not individual companies (DKE, BSI, ANSI,...)***
  - ***> 8000 standards for all sorts of electrotechnical applications***
    - ***Photovoltaics***
    - ***Nanoelectronics***
  - ***Worldwide standards***
  - ***Consensus process: votes by country***
  - ***Cycle time: 36 months***

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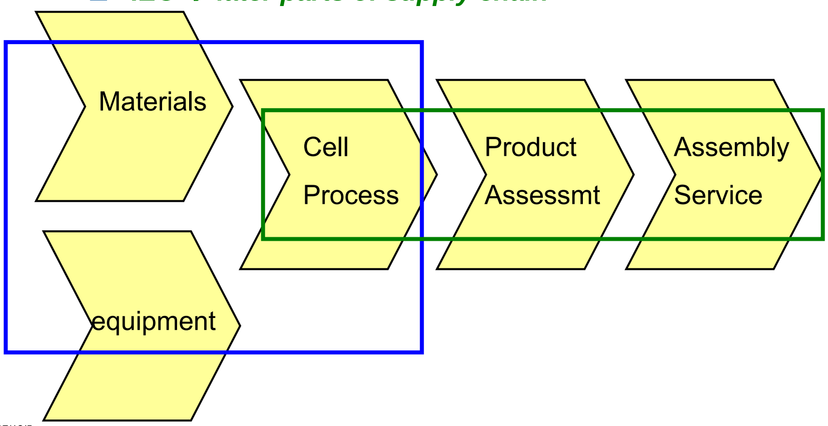
How

- **Which SDO should do what?**
  - ***SEMI → early parts of supply chain***
  - ***IEC → later parts of supply chain***



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How

- **Standards and emerging technology?**
- **Example 1: Chip industry transition from 200mm to 300mm wafers**
- **Example 2: Nanoelectronics**

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How

200mm → 300mm

- **Consortium of 14 companies: I300I**
- **Development of a whole suit of anticipative standards**
- **Results: Best practice generic process for**
  - Si wafers specifications including wafer mark
  - Wafer carriers and mechanical interfaces
  - Software and performance standards
- **Saved many million dollars per 300mm fab** !

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How

200mm → 300mm: Usage of standards

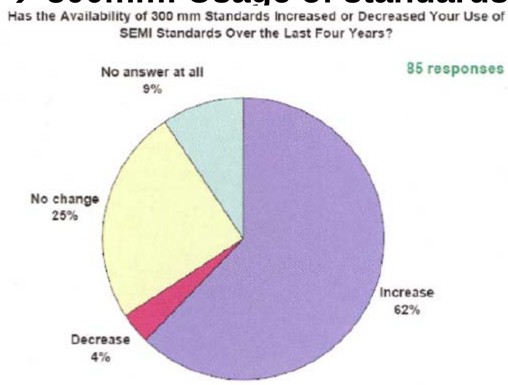

Figure 2a – Increase in use of standards
(300 mm standards have significantly increased the use of standards in the semiconductor industry)

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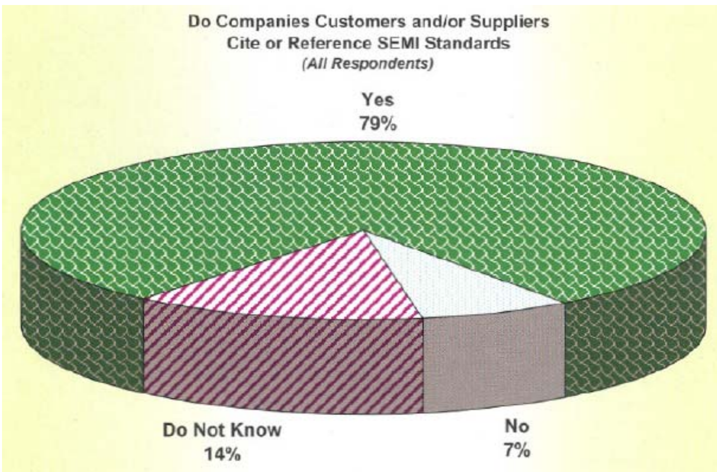
How

200mm → 300mm: Usage of standards



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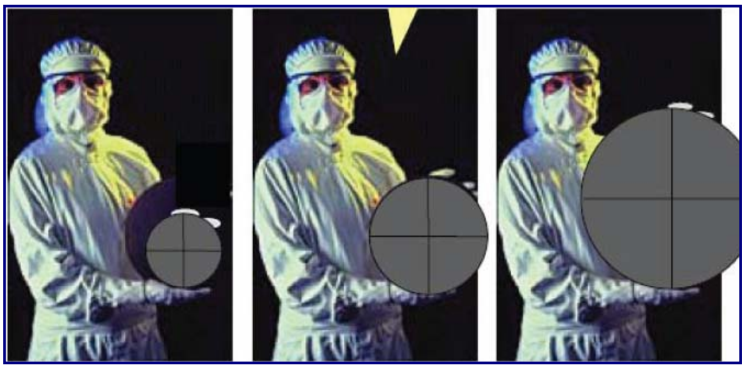
How

300mm → 450mm:

standards work starts now, production in 2014



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How

Example 2: Nanotechnology

- ISO TC 229 started up in 2006
- IEC TC 113 started up in March 2007
- Several (joint) working groups on
  - Terminology
  - Characterization
  - Environment, Health, Safety
  - Performance assessement (for nano-enable electronic feature)

- PV: cells based on TiO_2 and Carbon Nano Tubes are on offer already now!

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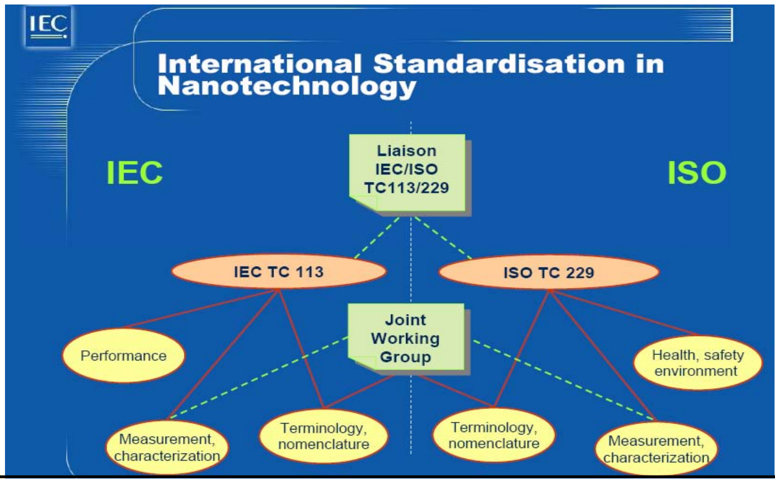
How

Example 2: Nanotechnology



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Take Home Message

- Standards as a „best practice“ Supply Chain elements
- Based on voluntary cooperation between industry volunteers and other stakeholders
- SEMI: Materials, Equipment, Process
- IEC: Product and Product performanc
- It is never too early for standardization
- Microelectronics: Guestimate 10- 30% savings 200mm→ 300mm

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PV CYCLE

Motivation, Objective and Benefits

3rd International Thin Films workshop

Daniel Fraile

European Union Waste Policy

Principle: The industry must be responsible for its products

- WEEE: Directive 2002/96/EC on Waste Electrical and Electronic Equipment
- RoHS: Directive 2002/95/EC on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment

- Both directives entered into force on 13 February 2003 and require Member States to transpose their provisions into national law by 13 August 2004

WEEE Directive

- **Objectives: The prioritiy of this directive is the prevention of production of wastes from electrical and electronic equipment (WEEE) and their reuse, recycling and recovery of such wastes so as to reduce disposal.**
- **Each producer is responsible for financing the collection, treatment, recovery and disposal of its own products**
- **The scope of the Directive is defined in Annex IA/IB: PV modules are not listed in Annex IA/IB**
- **Legal basis: Article 175 EC Treaty**

Revision of the WEEE Directive

- Two studies have been organized by the EC in order to prepare the revision of the WEEE directive (2008):
  - **"2008 Review of Directive 2002/96/EC WEEE":**
    Contractor: Institute of Environment and Human Security of the United Nations University (UNU-EHS), appointed in September 2006.
  - **The producer responsibility principle of Directive 2002/96/EC WEEE**
    Contractor - ÖKOPOL – Institut für Ökologie und Politik GmbH - on December 2006

ROHS Directive

RoHS: Directive 2002/95/EC on the Restriction on the Use of Certain Hazardous Substances in Electrical and Electronic Equipment

- Member States shall ensure that, from 1 July 2006, new electrical and electronic equipment put on the market does not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).
- Legal Basis: Art. 95 of the Treaty

Review of the ROHs Directive

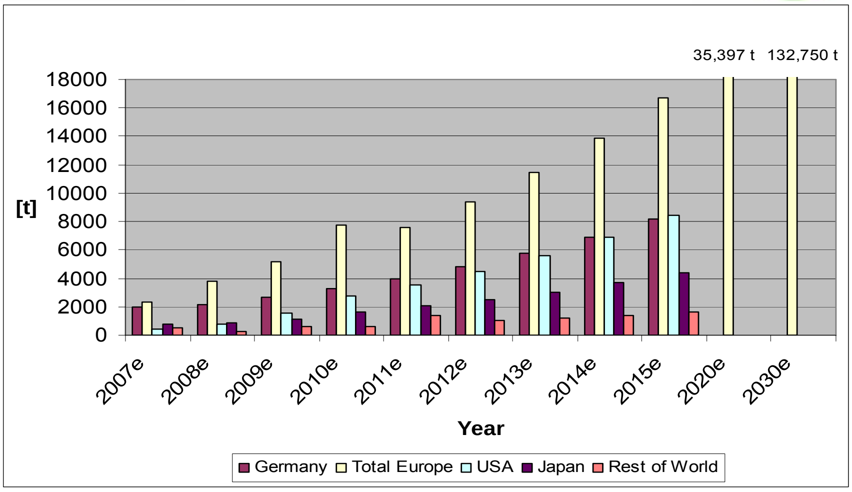
Possible objects of the review: scope of the directive, substances covered

- May 2007: Consultation with stakeholders- end of the first stage.
- 2008: Consultation with stakeholders on options for the revision of the Directive
- Late 2008: expected presentation of the legislative proposal for the review of the ROHs directive

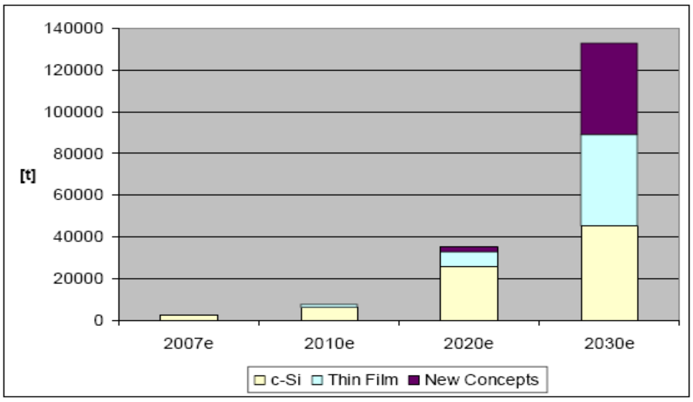
Motivation to found PVCYCLE

- EU legislation and transposition to the national laws
- Environmental producer responsibility
- Maturity of the industry

Waste Forecast By Weight



Waste Forecast



(source: Solar World)

Environmental targets

As a renewable energy source, PV industry must contribute with convincing solutions to the protection of the environment
by promoting increased use and sustainability of PV technology.

The PV industry must meet the global climate protection requirements.

Necessary:

•Sustainable solutions along the whole value chain

•General waste management and recycling policy
•guaranty the highest economically feasible collection and recovery rates
•appropriate treatment of waste PV modules

PV CYCLE Association

- Founding of PV CYCLE Association 2007-07-05 in Brussels

  (EPIA & BSW with the support of 6 PV companies at the beiginning)
- The association is established as a nonprofit international

  management system
- Organized under private law
- financed by the fees of its members

Aims

- Structuring of best paths and methodologies for waste management of PV modules under consideration of national and international legislation
- Elaborate immediately a voluntary take back and recovery system for PV modules
- Evaluation of best practice standards for logistic structures
- Support of research projects (e.g. IEA PVPS Task 12)
- Ensure regularly monitoring
- Public relations in the field of sustainable production and PV waste treatment
- Collection and publication of environmental relevant data

Benefits

- Secure the positive image of PV and therefore the public support of the PV market
- Avoid unfavorable and expensive waste regulations

Revision object of two studies, results have been published on 15th november 2007:

None of these two studies suggest the inclusion of PV modules in the scope of the WEEE Directive.

Tasks

Short term tasks | Long term tasks

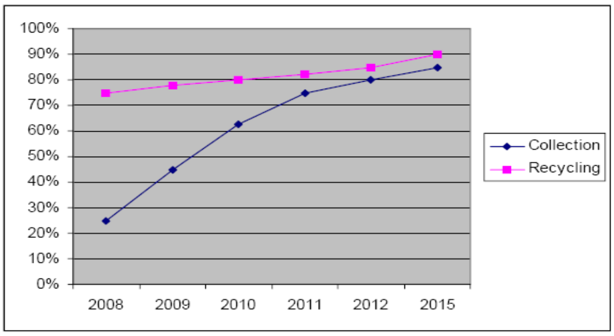
1 – 2 years

Short term tasks: Establishment of a voluntary take back and recovery system for PV modules

Long term tasks:
- Operation of take back system
- Provide solution for possible environment, health and safety issues

Long term tasks

- Clearly competitive advantage in the market for PV CYCLE members
- Preparation of verifiable databases of PV issues
- Realization of highest collection and recovering rates (example):



Next Activities

Fill the position of the general secretary	2007-end
Formation of working groups	2007-end
Establishment of the take back system	2008
Start of collection	2008

Members

All PV companies with accountability for photovoltaic waste, (e.g. manufacturers, importers and suppliers along the entire value chain of PV products) can become members of the association.

High market share of PV manufacturers ⇐

Current Members:

- Avancis
- BP Solar
- Conergy
- First Solar
- Isofoton
- Kyocera
- Q-Cells
- Sanyo
- Schott Solar
- Scheuten Solar
- Sharp
- Solarfabrik
- Solarworld
- Solon AG
- Solyndra
- Sulfurcell
- Sunways
- Würth Solar
- **EPIA**
- **BSW**
- **ECN**

Thanks for your Attention

Further information: www.pvcycle.org

ASSOCIATION

PV CYCLE

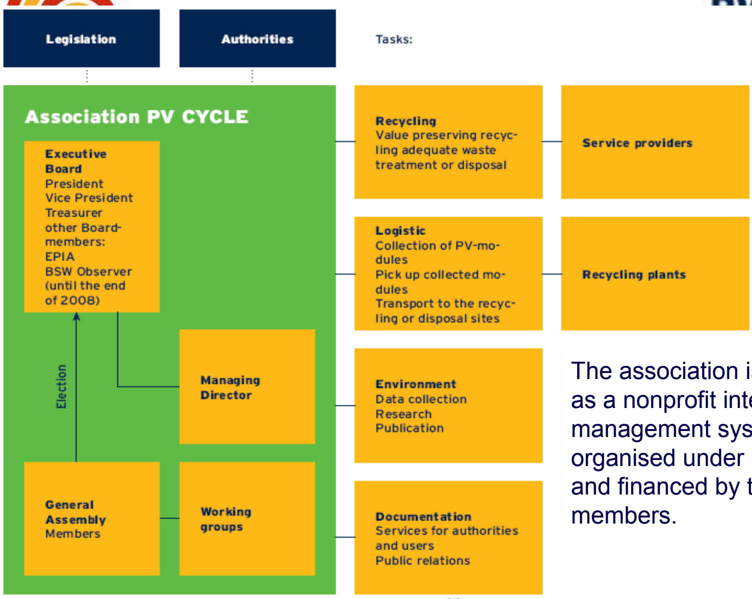
History

2003	First publications on waste treatment, WEEE, life cycle issues voluntary take back systems with kind support of JRC, IES and EPIA Ökopol Study on waste treatment of modules
2004	Workshops on waste, LCA, WEEE and take back systems Ongoing work in SP6 of EU project “CRYSTAL CLEAR“
2005	First PV CYCLE initiative supported by EPIA and BSW, creation of working group PV CYCLE First initiatives for IEA PVPS Task 12
2006	Drafts of Statutes and Business Plans
2007	Study PVCYCLE supported by BMU, Germany Foundation of PV CYCLE Association

WEEE Directive

- Most important provisions
- Art. 2: scope of the directive
- Annex I A: categories of EEE that fall within the scope of the directive
- Annx I B: list of products belonging to categories in Annex IA to which the Directive applies
- Art. 5: rate of separate collection of at least four kilograms on average per inhabitant per year of WEEE from private households
- Art. 6: treatment
- Art. 9 financing of WEEE collection and treatment

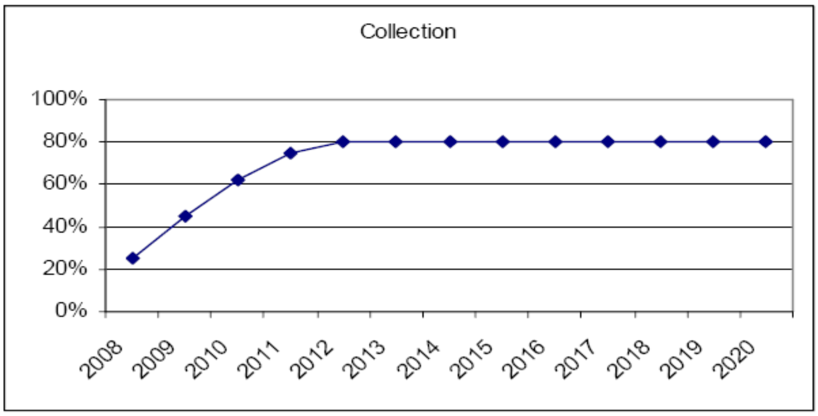
Structure



The association is established as a nonprofit international management system which is organised under private law and financed by the fees of its members.

PV CYCLE

- Collection/Recycling Targets (Collection Rate)



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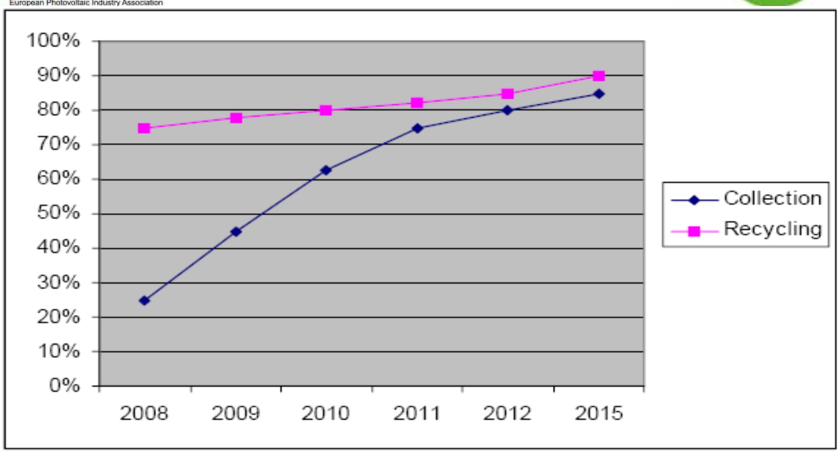
PV CYCLE

- Collection/Recycling Targets (Recovery Rate- Example)



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Founding members

- Avancis
- Conergy
- Isofoton
- Schott Solar
- Solarworld
- Sulfurcell

- EPIA
- BSW

Objectives

- **Promote the protection of the climate and the environment in enhancing increased and sustainable use of PV technology.**

- **Create a positive environment for the ongoing growth of the PV industry**

- **Install an overall waste management policy**
  - guarantees highest economically feasible collection and recovery rates
  - appropriate treatment of waste PV modules.

Next Tasks

- **Implementation of the take-back system**
  - Concept development and implementation
  - Call for tenders, selection of the service providers
- **Operation of the take-back system**
  - System management
  - Scheduling and controlling the take-back volumes and waste volumes
  - Controlling the service provider
  - User support
  - Auditing and certification of the system
  - Continuous enhancement of the system

WEEE Directive
Current development

WEEE will be revised in 2008

- Possible object of the revision: scope
- Procedure: codecision.
- Key actors: Parliament, Commission, Council

ROHS Directive

- **Current Developments**
- **Review of the Directive**
- **Possible objects of the review:** scope **of the directive,** substances **covered**

Current Activities

Commun agreement of EPIA-BSW members to do:

- Assessment to identify which are the most appropiate solution for the PV industry for waste treatment (take back system).
- Lobbying Activities

Survey Status

START
20th May 2007

FIRST OUTCOMES
mid of July 2007

END
End of October 2007

- **Co-financed by EPIA, BSW and BMU**

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Survey Structure

1. Background and framework.
   - PV Market, technologies, industry, Policy framework, WEEE&RoHs, take back systems, possible reaction
2. Recycling processes and techniques
   - Cristalline cells, thin film, perspective
3. Option: Voluntary system
   - Take back system, recovery system, carrier organization, legal and juridical aspects
4. Option: WEEE
   - Legal consequences, etc.
5. Options
   - Business as usual with WEEE and without WEEE
6. Overall summary and recomendations (30/10/07)

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Survey Partners

- EPIA
- BSW
- Ökopol
- Dörte Fouquet
- ZSW
- Deutsche Solar
- Sharp
- Isofotón
- First Solar
- Würth Solar

- Revision object of two studies, results have been published on 15th november 2007:

  None of these two studies suggest the inclusion of PV modules in the scope of the WEEE Directive.

PV-Cycle: Overview Thin Film

- PV-Cycle Association
- PV-Cycle Study
- Recycling Technologies for Thin Film PV
- Summary

PV-Cycle Association: Statutes

- Statutes:

  Section 2 : Purpose and Principles:

  ...

  (8) The Association wants to ensure non discriminatory take back and recycling systems which guarantee best possible solutions at best cost- and technology- efficient level for all PV technologies, non regarding their market share

PV-Cycle Association: Bye laws

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CISfab powered for the future

1. Membership fee

1.1. The fiscal year of the Association shall be the calendar year. The payment of the membership fee shall be due on 31 March each year.

1.2. The annual membership fee of the members of the Association shall be calculated as follows according to their respective category:

Membership category	Turnover in the PV module business in Europe of the member in the previous calendar year	Annual fee
Full member category I	>100 Mio €/a	25.000 €
Full member category II	10-100 Mio €/a	12.500 €
Full member category III	<10 Mio €	5.000 €
Associated members		Minimum 1.000 €

In the founding year 2007, a full annual fee has to be paid in order to build up the association. If a company becomes a member during the following years it has to pay the full annual membership fee.

PV-Cycle Association: Bye laws

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2. Voting rights in the General Assembly

2.1. Only full members are entitled to vote.

2.2. The voting rights for full members are allocated as follows, according to their category as defined in article 1.2. above:

Category	Voting rights
Full member category I	3
Full member category II	2
Full member category III	1

PV CYCLE

PV Cycle

1st Extraordinary General Assembly

16 October 2007,
CENELEC
35, Rue de Stassartstraat
B-1050 Brussels, Belgium,

List of Members of PV Cycle

Full Members

Nr	Company	Status	Nr of votes
1	AVANCIS ●	Full member	1
2	BP Solar	Full member	3
3	Conergy	Full member	3
4	EPIA	Full member	1
5	First Solar ●	Full member	3
6	Isofoton	Full member	3
7	Kyocera	Full member	3
8	Q-Cells	Full member	1
9	Sanyo	Full member	3
10	SCHOTT Solar	Full member	3
11	Sharp	Full member	3
12	Solar-Fabrik AG	Full member	2
13	Solarworld	Full member	3
14	Solon AG fur Solartechnick	Full member	3
15	Solyndra ●	Full member	1
16	Sulfurcell ●	Full member	1
17	Sunways	Full member	2
18	Würth Solar ●	Full member	2

Associate Members

● : Thin film

Nr	Company	Status
1	BSW	Associate member
2	Energy Research Centre	Associate member

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General Assembly:

16.10.2007 (Brussels)

Aprox. 80% of module manufact. represented

President:

Dr. K. Wambach, Deutsche Solar

Representative for Thin Film:

Pierre Yves Le Borgn (First Solar), located in Brussels

PV-Cycle, general assembly
goals / time schedule / first cost estimates

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Take back 2008-2011

Europe		2008		2009		2010		2011	
	Eur/MWp	amount	costs/Eur						
modules newly installed/MWp		1110		1400		1656		1938	
waste amount/t		3807		5146		7774		7591	
waste amount/Wp		51	200998	69	518669	104	1243872	101	1639660
collection quota		25,00%		45%		62,50%		75%	
recycling quota		75,00%		78%		80%		82%	
collection costs/Wp	9000		114203		277858		583065		683191
collection costs/t			120		120		120		120
recycling costs/Wp			200998		518669		1243872		1639660
thin film	60000	8%	60908	10%	185239	15%	583065	20%	910922
cryst. Si	12000	92%	140089	90%	333430	85%	660807	80%	728738
recycling costs/t			211		224		256		288
thin film			800		800		800		800
cryst. Si			160		160		160		160
Total									
Total costs	81000		315201		796527		1826937		2322851
Total costs/MWp			24840		25800		28200		30600
Total costs/t			331		344		376		408
Costs to be added to modules newly put to market/ €/Wp:			0,000284		0,000569		0,001103		0,001199

no transport of single modules
sureties not included

Data: general assembly, K. Wambach, Deutsche Solar

PV-Cycle, general assembly

goals / time schedule / first cost estimates

Plans for 2008:

- Individual recycling on company level
  - ⇨ figures (recycling path, amounts, cost) have to be made transparent to PV-Cycle
- PV-Cycle Association will charge a professional company to setup a recycling system (solution for collection place , - boxes, labelling, system monitoring, ...)

PV-Cycle: Study

- Study shall be finalized by 30.11.2007
- Study will be distributed
- Few Preliminary results

Structure Study

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PV-Cycle Study: Scenarios and their costs

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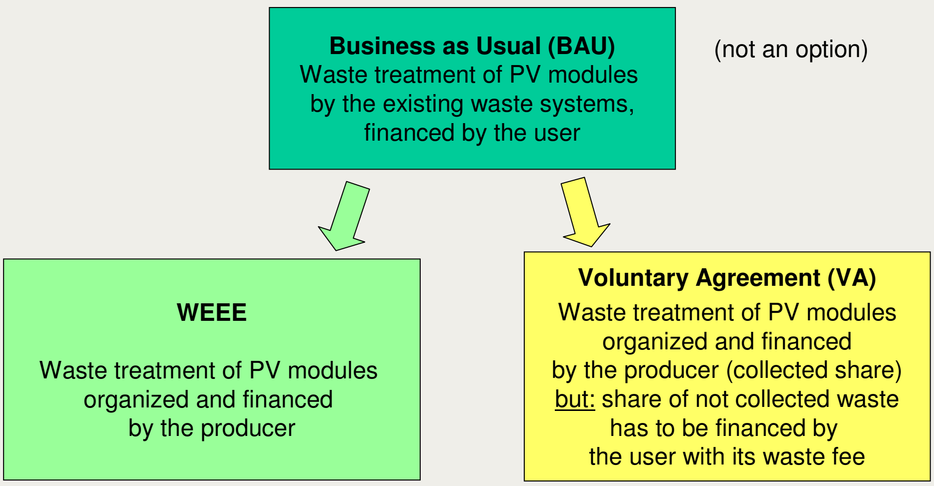
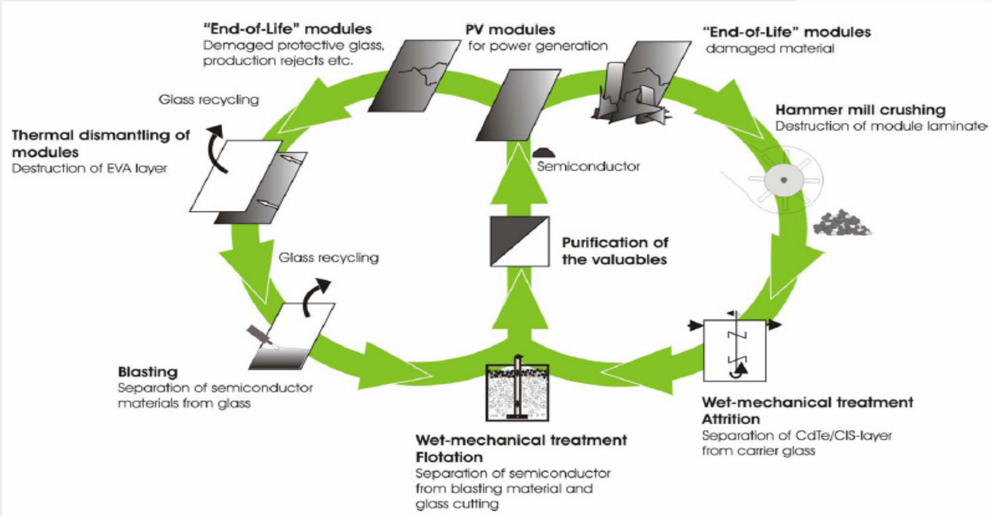
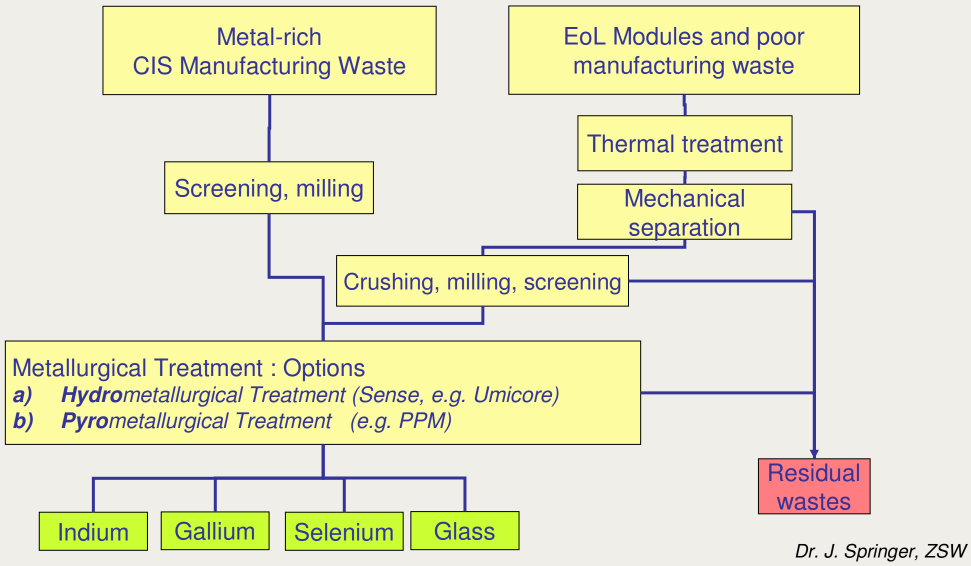


Recycling Technology: EC funded Project "RESOLVED"

RESOLVED
Recovery of Solar Valuable Materials, Enrichment and Decontamination - RESOLVED



Recycling Technology: Outline of the recycling process for CIS TF modules (mainly developed in "SENSE")



Dr. J. Springer, ZSW

Recycling Technology: FIRST SOLAR

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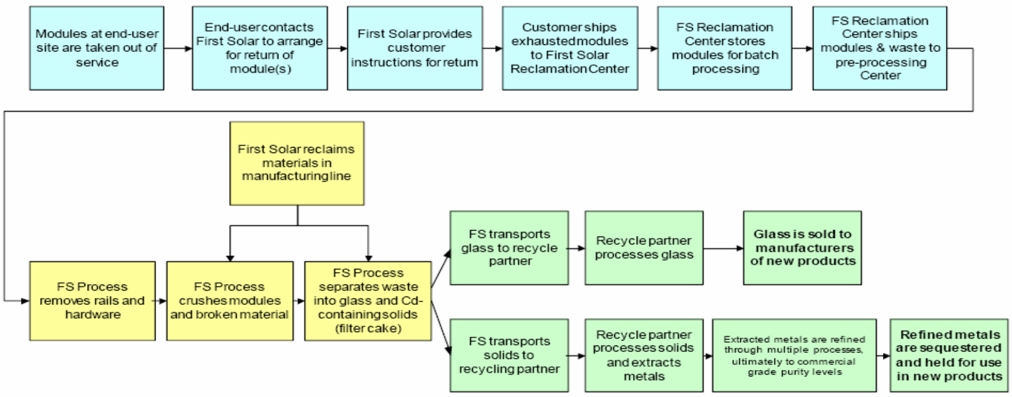

First Solar will open it´s recycling system for other companies (announcement Pierre Yves Le Borgn at general assembly)

Recycling Technology: a-Si

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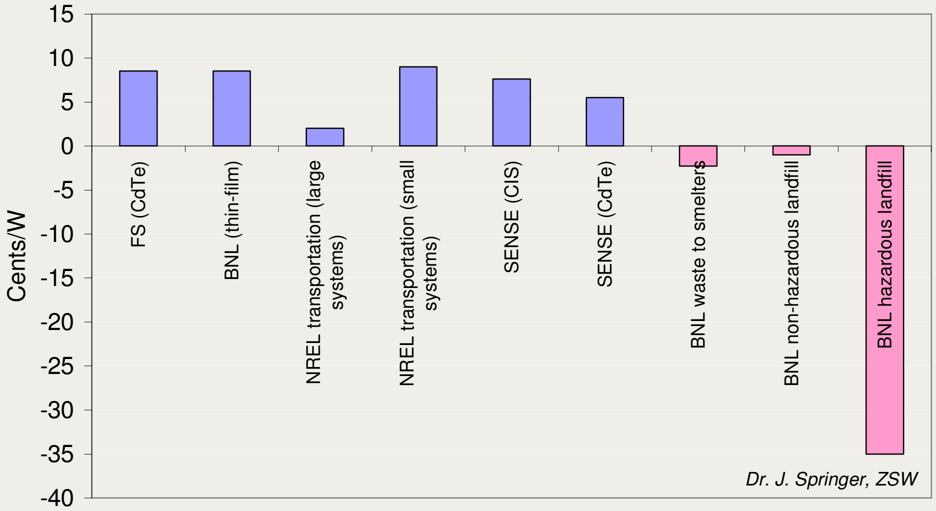
- Recycling technology for a-Si, a-Si/µ-Si ?
- Recycling for a-Si on foil ?

  ⇨ Input to PV-Cycle

Recycling Costs and Avoidable Costs



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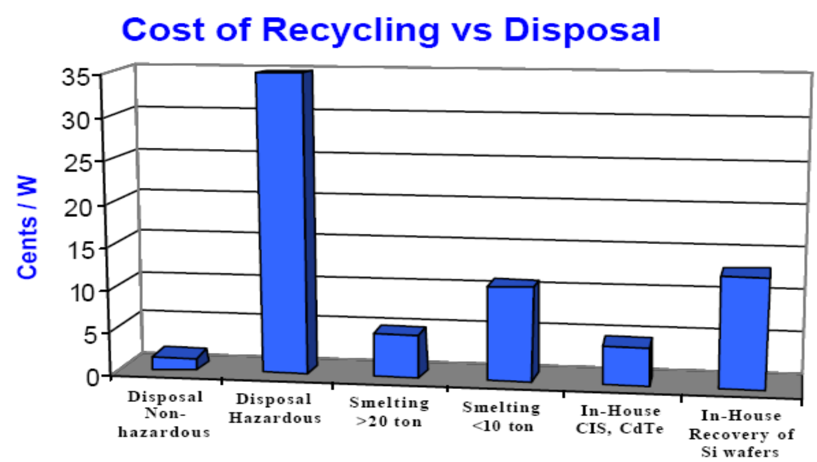
CdTe and CIS Recycling costs (Zweibel, BNL)



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Summary

- improve participation of thin film industry in the PV-Cycle association
  ⇨ get member of PV-Cycle
- Use Recycling as marketing instrument
  ⇨ PV is a real green technology
- Improve / set up recycling technology
  ⇨ use test phase 2008

IP PERFORMANE PROJECT

A science base on PV performance for increased market transparency and customer confidence

ISPRA, 23 November 2007

Daniel Fraile

PERFORMANCE
PV Modules and Systems –
Measurements, Quality, Standardization

is an EU co-funded project with

Total Budget	11.8 Mio €
Number of partners	28
Start date	01 January 2006
Duration	4 years

Project partners: Research

- •Fraunhofer ISE, Freiburg, DE
- •PSE, Freiburg, DE
- •CIEMAT, Madrid, ES
- •WrUT, Wroclaw, PL
- •Joint Research Centre, Ispra, IT
- •TÜV, Cologne, DE
- •ECN, Petten, NL
- •CREST, Loughborough University, UK
- •CEA-GENEC, Cadarache, FR
- •SUPSI-TISO, Canobbio, CH
- •UNN-NPAC, Newcastle, UK
- •ZSW, Stuttgart, DE
- •Arsenal, Wien, AT
- •Ben Gurion Univ., Beer Sheva, IL
- •Tallin Univ., Tallin, EE
- •FH Magdeburg, Magdeburg, DE
- •SP, Boras, SE
- •PCCL, Leoben, AT
- •Ecofys, Utrecht, NL

Project partners: Industry

- •EPIA, Brussels, BE
- •Isofotón, Malaga, ES
- •Würth Solar, DE
- •Phönix Sonnenstrom, Sulzemoos, DE
- •Conergy, Hamburg, DE
- •RWE Schott Solar, Alzenau, DE
- •Scheuten Solar Systems, Venlo, NL
- •MeteoControl, Augsburg, DE
- •IT Power, Basingstoke, UK

Why do We need PERFORMANCE?

•Comparability of cell and module measurements?

•Annual yields and yield predictions?

•Module lifetime?

•Degradation?

•New technologies (a-Si, CdTe, CuInSe, CuInS…)?

Justification

There is much knowledge on measurement and testing procedures as well as PV PERFORMANCE prediction and assessment, but

- it is not integrated from production to application
- it is not implemented in real life
- it is often not helpful in the daily life
- there is not sufficient knowledge concerning thin-film technologies
- thereby it is not sufficient for industry and market needs in a multi gigawatt market

Approach

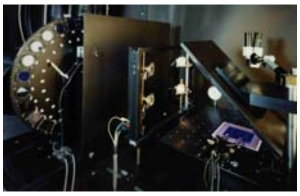
PERFORMANCE provides the necessary knowledge and methods to fulfil the markets needs for transparency and planning safety

- Improvement of yield predictions
- Harmonising of measurements and tests
- Considering new (thin-film) technologies
- Life-time and Quality
- Modules and System

8 Subprojects:

1: Traceable performance measurements of PV devices
2: Energy delivery of PV devices
3: Performance assessment and evaluation of PV systems
4: Modelling and analysis
5: Service life assessment of PV modules
6: PV as a building product
7: Industry interaction and dissemination
8: Standardization processes

Subproject 1: Traceable performance measurements of PV devices



- Improvement of measuring and calibration methods
- Harmonising of measuring methods between test labs and industry
- Development of guidelines for power characterisation of PV cells and modules
- Adaptation of measurement procedures for new and emerging technologies (thin film cells, multijunction cells, back contact silicon cells, etc.)

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Subproject 2: Energy delivery of PV devices

- Bridge the gap between indoor STC measurements and outdoor `real world´ measurements for any place in Europe
- Determination of annual module energy yield from a minimum set of measured parameters

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Subproject 3: Performance assessment and evaluation of PV systems

•Analysis of system performance data towards an understanding of yields and losses

•Analysis of system performance data towards an understanding of long term stability

•Harmonisation / adaptation of guidelines for plant monitoring and operation surveillance

•Assessment of different approaches towards `guaranteed results´

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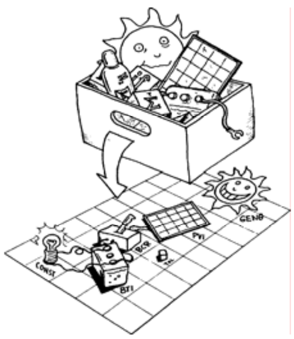
Subproject 4: Modelling and analysis



•Development of a coherent set of models of PV module and system performance

•These models will translate PV module data and PV component data into system performance figures and link to long term data sets of ambient conditions

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Subproject 5: Service life assessment of PV modules

- •Develop ageing models based on `real life´ stress factors
- •Develop new accelerated ageing procedures
- •Facilitate innovation in module technology
- •Provide manufacturers with service life data for setting their guarantee specifications
- •Increase planning reliability

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Subproject 6: PV as a building product

•Assessment of standards and performance requirements for building integrated PV modules towards
(a) mechanical stability,
(b) electrical safety,
(c) fire safety

•Suggestions for module technologies which fit into the existing codes of the building industry

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Subproject 7: Industry interaction and dissemination

- Identify the needs of PV markets, producers, installers, customers and investors
- Accelerate feedback loops between industry and standardisation processes
- Communicate project results to industry, politics and users in a rapidly growing market

Industry interaction

- EPIA is full consortium member
- EPIA appointed one company as industry contact for each technical SP

SP1: Isofotón
SP2: Shell Solar / Würth Solar
SP3: Phönix Sonnenstrom
SP4: Conergy
SP5: Schott Solar
SP6: Scheuten Solar Systems

Subproject 8: Standardisation processes

- Contribute to revision of standards
- Initiate new standards
- Develop a long term vision for European standardisation

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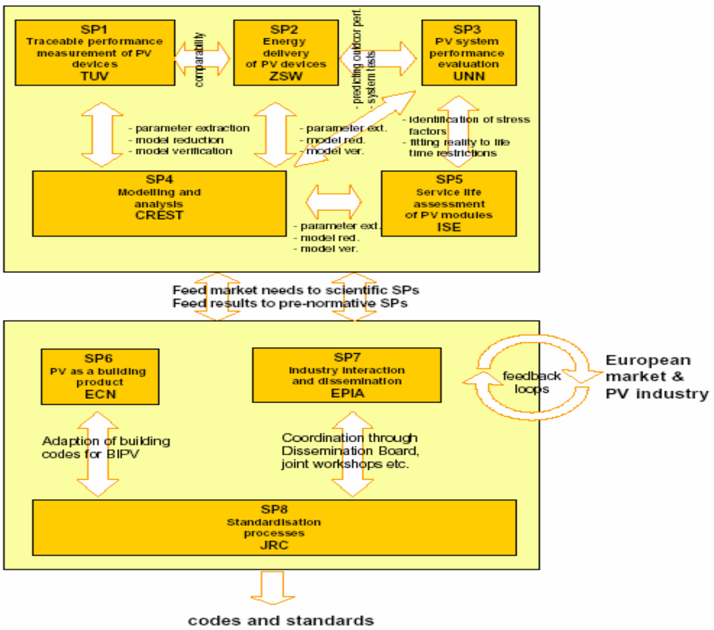
Interdependencies



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Upcoming Workshop

- Topic: Energy Rating and Performance Standards of PV Modules
- Place& Date: 12th December 2007, Berlin
- Further information:

  www.pv-performance.org
  www.epia.org

Thin Films workshop ISPRA, 23rd November 2007

Thanks for your attention!

Thin Films workshop ISPRA, 23rd November 2007

The Current Situation of International PV Standards

Dr. Ewan D. Dunlop
European Commission JRC

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IEC Origins , St. Louis Declaration, 1904

- *"That steps should be taken to secure the co-operation of the technical Societies of the world by the appointment of a representative Commission to consider the question of the standardization of the Nomenclature and Ratings of Electrical Apparatus and Machinery."*
  - IEC Statutes drawn up London 1906
    - Lord Kelvin, 1st President

PERFORMANCE

From the CENELEC history pages at http://www.cenelec.org

- …"It is actually the ancient EEC that raised, for the first time, the idea and need to coordinate and harmonize standards in all EEC member countries in order to achieve a common market for electrotechnical goods…." This principle is reflected in the Treaty of Rome itself, where ***Article 100*** is of capital importance: **"*Member States resolved unanimously to abolish existing trade barriers created through legislation and standardization*".**

By the end of 1959, some principles, which are still valid today, had already been drawn up:

Priority to **IEC** work wherever possible
Mutual information on new national work
Technical co-operation in technical groups
Cooperation in testing and certification

IEC TC 82 and CENELEC TC 82

- Established 1981,
- WG 1, WG 2, WG 3
- WG 4
- WG 5, WG 6, - WG 4,
- \- WG 5, WG 7
- More than 60 Standards Published (2.5 per year)

- CENELEC TC 82 have published , adopted some 30 documents

PERFORMANCE

Scope of IEC TC 82

- To prepare international standards for systems of photovoltaic conversion of solar energy into electrical energy and for all the elements in the entire photovoltaic energy system.
- In this context, the concept "photovoltaic energy system" includes the entire field from light input to a solar cell to and including the interface with the electrical system(s) to which energy is supplied

In particular:

- characteristics of the radiation input
- solar electric conversion devices
- energy storage and power conditioners
- the interface with the electrical system(s)
- the interconnection equipment and materials
- system integration and project management.

TC82 and the last 25 years

- 2006:
- 1700 MW_p(31%/yr)
- 5000 MW_p Total
- 5 $\$_{2002}$/ W_p (-6.5 %/yr)

- 1981:
- 18 MW_p
- 30 MWp Total
- 25 $\$_{2002}$ / W_p

TC82 and the PV Future

- 2010: 10 GWp / yr (40%/yr)
- 2020: 100 GWp / yr (26%/yr)
- Major Markets:
- Professional Grid for Peak Demand
- Rural Electrification

Anticipate Needs form IEC Chairman Presentation 2007

- Lifetime Energy Production
  - How many years to pay back investment?
- Reliable Electricity Delivery in Rural Regions
  - How to Design Complex Hybrids?
- Reduce Costs of Building Integration
  - How to avoid the trap of labour costs?
- Meet Environmental Standards
  - How to meet the expectations for clean energy?

PERFORMANCE

Lifetime Energy Production

- Global Market Value of Calibration:
- ± 2% equivalent to ± 500 Mio$ revenue in 2010, when 10 GW are produced

	Today		Future
Peak Power	(± 2%)	*Calibration*	(>1%)
Yearly Yield	(± 10%)	*Energy Rating*	(>5%)
Equivalent Lifetime	(± 30%)	***EoL testing?***	**(?)**

PERFORMANCE

Trade Barriers

- Global/ European Markets:
  - Wafers, Cells, Modules, BOS, Systems
  - Building Integrated components
- Major Technical Barriers Do Exist:
  - Inverters (2006 sales: ~ 600 Mio$)
  - Grid interface
  - Safety
  - EMC, Recycling/ Disposal, Env.friendly Mat.
  - Project Management / Design Quality

International Schemes

IECEE

Worldwide System for Conformity Testing and Certification of Electrical Equipment and Components (IECEE)

> "The Scheme is intended to reduce obstacles to international trade which arise from having to meet different national certification or approval criteria. Participation of the various NCBs within the Scheme is intended to facilitate certification or approval according to IEC standards. "

"mutual recognition"

Calibration Traceability and Power Determination

Work in progress by TC 82 Project	IP Performance sub Project link in order of importance
IEC 60904-2 Ed. 2.0 Photovoltaic devices - Part 2: Requirements for reference solar devices	**SP1, SP2 , SP3**
IEC 60904-3 Ed. 2.0 Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data	**SP1,SP2, SP4, SP3**
IEC 60904-4 Ed. 1.0 Photovoltaic devices - Part 4: Procedures for establishing the traceability of the calibration of photovoltaic reference devices	**SP1,**

Calibration Traceability and Power Determination (2)

Work in progress by TC 82	IP Performance sub Project link in order of importance
IEC 60904-7 Ed. 3.0 Photovoltaic devices - Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices	**SP1,SP2, SP4, SP3**
IEC 60904-9 Ed. 2.0 Photovoltaic devices - Part 9: Solar simulator performance requirements	**SP1,SP2, SP4,**
IEC 60904-10 Ed. 2.0 Photovoltaic devices - Part 10: Methods for linearity measurements	**SP1,SP2, SP4,**

Performance Measurement and Energy Rating

IEC 60891 Ed. 2.0 — **SP2, SP1, SP3, SP4,**

Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic devices

IEC 61853 Ed. 1.0 **E** **PWI** — **SP2, SP1, SP3, SP4, SP6**

Performance testing and energy rating of terrestrial photovoltaic (PV) modules

Lifetime Type Approval and Product Quality

IEC 61646 Ed. 2.0 — **SP5, SP1, SP2, SP4, SP6**

Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval

IEC 62108 Ed 1.0 — **SP5**

Concentrator photovoltaic (CPV) modules and assemblies - Design qualification and type approval (IEC 62108 Ed. 1)

IEC 62145 Ed. 1.0 — ***SP5, SP1 SP2***

Crystalline silicon terrestrial photovoltaic (PV) modules - Blank detail specification

IEC 62234 Ed. 1.0 — **SP6, SP5**

Safety guidelines for grid connected photovoltaic (PV) systems mounted on buildings

Integration and System Performance Issues

IEC 61829 Ed. 2.0 — **SP2, SP3, SP4**

Crystalline silicon photovoltaic (PV) array - On-site measurement of I-V characteristics

IEC 62109-1 Ed. 1.0 — **SP3, SP6, SP5**

Safety of power converters for use in photovoltaic power systems - Part 1: General requirements

IEC 62109-2 Ed. 1.0 — **SP3, SP6, SP5**

Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters

IEC 62109-3 Ed. 1.0 — **SP3, SP6, SP5**

Safety of power converters for use in photovoltaic power systems - Part 3: Controllers

IEC 62116 Ed. 1.0 — **SP3, SP6,**

Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters

PERFORMANCE

Selected Highlights of on going activities

Ewan D Dunlop

European Commission JRC

PERFORMANCE

PERFORMANCE IP

SP1
Traceable performance measurement of PV devices

W. Herrmann

TÜV Rheinland Group, 51101 Cologne, Germany
Phone: +49.(0)221.806-2272
Email: werner.herrmann@de.tuv.com

Research objectives in SP1

- Set up traceability chains of indoor characterisation of PV module in both test labs and PV industry
- Improvement of the comparability of measurement results between test labs (ultimate goal ±1% for c-Si modules)
- Development of technology specific measurement/calibration procedures (high efficiency c-Si, thin film, multi-junction PV devices)
- Translation of research results into best practice and labelling guidelines for PV industry (5% tolerance for output power labelling of c-Si PV modules)

Work Packages in SP1

WP 1.1 Round-robin tests (TUV Rheinland)

WP 1.2 Solar simulator performance assessment (TUV Rheinland)

WP 1.3 Thin-film, multi-junction and novel devices (Fraunhofer-ISE)

WP 1.4 Measurement accuracy and traceability chain (EU Joint Research Centre)

PERFORMANCE

WP1.1/WP1.2 Research Approach

Round robin test with commercially available PV modules covering the range of current PV technologies (1. crystalline silicon, 2. thin-film):

- Identification of cell types
- Manufacture of test samples
- Definition of test programmes

Inventory of measuring equipment and documentation of measurement practices in test laboratories:

- Performance evaluation of solar simulators (on-site measurements)
- Questionnaires

Creation of experimental common data basis for analyses

Upgrade of measuring equipment for meeting the requirements of PV technologies

Development of technology specific measurement techniques

Translation to guidelines for PV industry and input to standardisation

PERFORMANCE

WP1.1 Round Robin Test (c-Si modules)

Cell manufacturer	Cell type	Cell dimensions / Efficiency	Cell inter-connection circuit of the module
SunPower Corporation SUNPOWER	A-300 back contact	125 x 125 mm (psq) Up to 21.5%	72s1p and 36s2p
Sanyo Electric Co. Ltd. SANYO	HIT Heterojunction with Intrinsic Thin layer	125 x 125 mm (psq) 18.7% (Module)	72s1p
Microsol International LL Fze. microsol SOLAR CELL DIVISION	MONO 156 MPSQ	156 x 156 mm (psq) Up to 15.7%	36s1p
Qcells AG Q.CELLS	Q8TT3-1580	210 x 210 mm 15.8%	36s1p
SCHOTT Solar SCHOTT solar	EFG 12530 Edge defined Film-fed Growth	125 x 125 mm 14.5%	72s1p

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WP1.1 Round Robin Test (c-Si modules)

Participating test laboratories

arsenal research
A Company of Austrian Research Centers

MINISTERIO DE EDUCACIÓN Y CIENCIA
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Fraunhofer ISE Institut Solare Energiesysteme

ESTI
European Solar Test Installation

SUPSI
Scuola Universitaria Professionale della Svizzera Italiana

TÜVRheinland®

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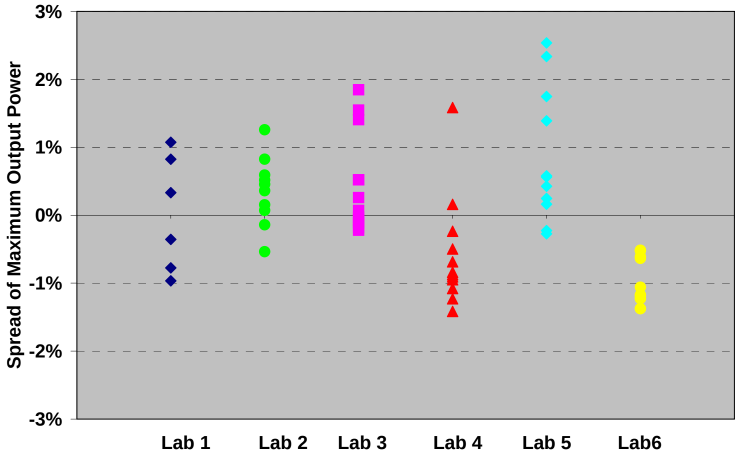
WP1.1 Round Robin Test (c-Si modules)
Test results



WP1.1 Round Robin Test (c-Si modules)
Major Conclusions

- **Good results regarding comparability:** The spread for reported P_{MAX} lies in the range ±2%. High or systematic discrepancies for laboratories could be either explained by deficits of the measuring equipment or measurement procedures.
- PV Industry expressed the need for additional information on calibration data of reference modules. **Test reports shall go beyond STC** and state how modules shall be measured to ensure an optimal transfer of calibration.
- There is **space for improvement**: The round-robin test together with solar simulator performance data provided a **comprehensive data basis and information source for labs** that can now be used for upgrading hardware and software regarding new technical requirements.

WP1.1 Round Robin Test (Thin-film modules) ⇨ Ongoing (March 2008)

Module/cell technology	Manufacturer	Module type
a-Si a-Si/a-Si a-Si/a-Si/a-Si	Kaneka SCHOTT Solar Unisolar	K60 (990 x 960 mm) ASI-F32/12 (762 x 605 mm) US-64 (1366 x 741 mm)
a-Si/µ-Si hybrid	Sharp Corporation	NA-850 WP (1130 x 935 mm)
CIS CIS	Würth Solar GmbH Shell Solar GmbH	WS 3110075 (1205 x 605 mm) Eclipse 80-C (1311 x 656 mm)
CdTe	First Solar	FS-50 (1200 x 600 mm)

PERFORMANCE

WP1.2 Solar simulator performance assessment

Variety of test equipment and measurement practices

- **Solar simulator equipment**: 1 steady-state, 5 pulsed (4 different types)
- 3 labs use a combined indoor / outdoor measurement procedure
- The **electronic equipment** for tracing the I-V curve is different in all labs
- **Multiflash measurement techniques** are available in 3 labs:
  2 labs → measurement of I-V segments, 1 lab → one I-V data point per flash
- **Variation of I-V data acquisition parameters**: All labs can measure both sweep directions. Preferred sweep direction is Isc ⇨ Voc (4 labs)
- Simulator suppliers use different filtering techniques to get a good **spectral match to AM1.5G** → Great variety in spectral irradiance distribution
- **Time for acquiring the I-V curve** ranges from 1.5 to 10 ms (pulsed systems)
- **Non-uniformity of irradiance** fulfils in all cases class A requirements of IEC 60904-9 for module sizes used in the round robin test (<2%)

PERFORMANCE

WP1.3 Thin-film, multi-junction and novel devices

- General: Reference devices?
- CdTe:
  Main problem: How to establish stable state? Long-term storage in the dark may require a long period of light exposure to recover.
- a-Si:
  Performance depends on actual history (temperature, irradiation) energy rating issues
- CI(G)S:
  Preconditioning important – technology specific procedures, relaxation time may depend on module efficiency
- Multi-junction:
  Dependence of IV-parameters on spectral distribution requires advanced measurement and calibration methods (current mismatch)

PERFORMANCE

WP1.4 Measurement accuracy and traceability chain

- Survey of actual practice of PV calibration traceability in labs available
- Principles of uncertainty analysis and evaluation of the traceability chain
  - Guide and Spreadsheet for calculation of uncertainty analysis developed
  - Wide range in final uncertainties for Pmax: 1.6% - 16%, 2.5% typical

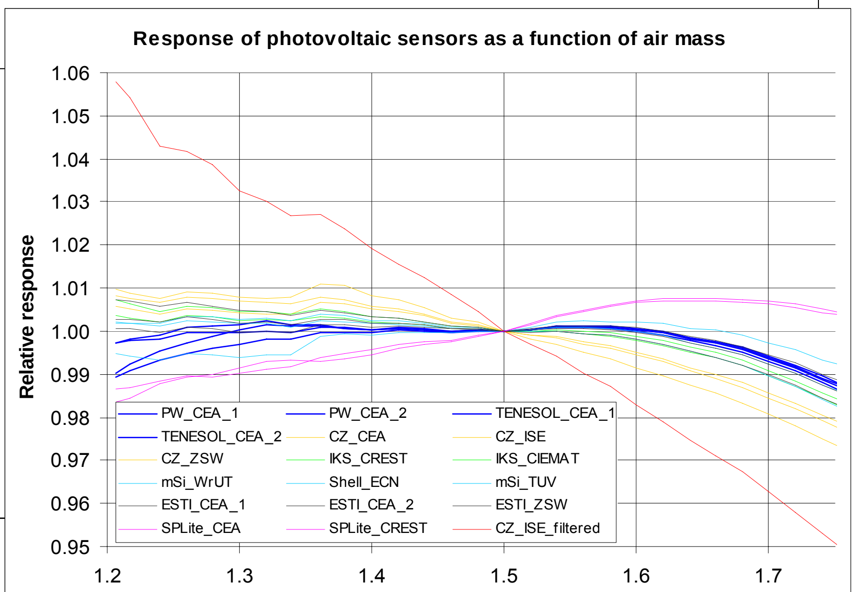
PERFORMANCE

Experimental SP 2

- Location: outdoor test facility of INES/CEA, (Cadarache, in south of France).
- 13 pyranometers and 19 reference cells
- Same plane outdoors.
- Sampling rate: 2 s
- Direct incidence

PERFORMANCE

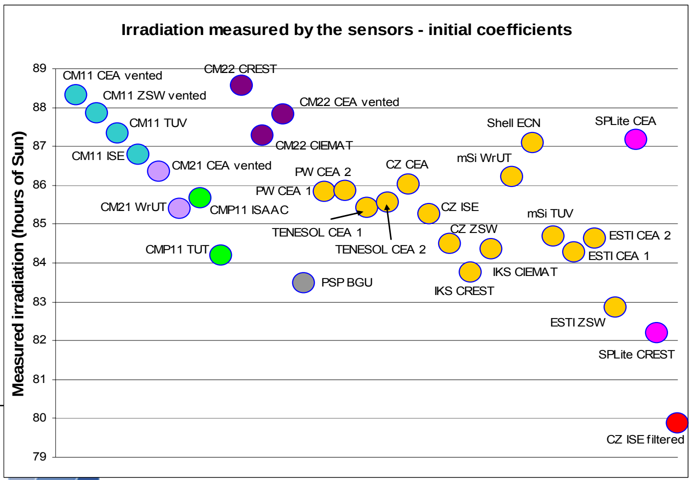
Spectral dependence



« Original » Calibration

Width of the 95 % confidence interval for the measurement of the solar irradiance:

► Pyranometers: 3.7 % ► reference cells: 4.2 %

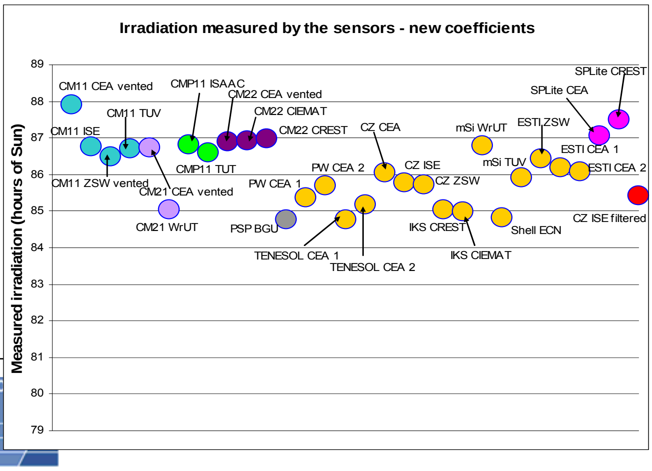


Recalibration at 1 sun

Width of the 95 % confidence interval for the measurement of the solar irradiance:

Pyranometers: 2.0 % reference cells: 1.9 %

Pyranometer	%
CM11 CEA vented	100.5%
CM11 ZSW vented	101.3%
CM11 TUV	101.0%
CM11 ISE	100.1%
CM21 CEA vented	99.6%
CM21 WrUT	100.4%
CMP11 ISAAC	98.7%
CMP11 TUT	97.2%
CM22 CEA vented	101.9%
CM22 CIEMAT	100.4%
CM22 CREST	101.0%
PSP BGU	98.5%

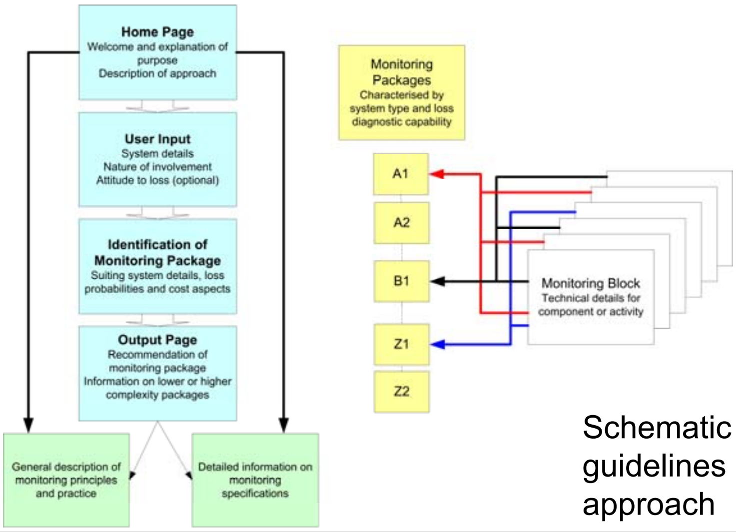


Conclusions

- Spread:
  - Pyranometers: 3.7 %   after recalibration: 2.0%
  - Reference cells: 4.2 %   after recalibration: 1.9%
- Intrinsic discrepancies remain!
  - Different temperature coefficients,
  - Dome effect for the pyranometers
  - Angle of incidence effects
  - Spectral dependence
- Recommendations
  - PV system monitoring should be based on cell of the same technology
  - Best solution:
    use device of the same manufacturing process

SP3 – PV System Performance Evaluation
SP Lead N Pearsall

- Developing modernised and harmonised European guidelines for the monitoring of PV systems of all kinds
- The guidelines will be web based and constructed from building blocks of instructions relating to different aspects of the system
- Work to date has included the development of the delivery concept, the commencement of drafting of the central building blocks (PV array, inverter etc.) and the definition of the nature and importance of fault mechanisms
- The new guidelines will incorporate the best practice of current monitoring services, whilst providing a framework for the development of enhanced monitoring activities



Schematic of guidelines delivery approach

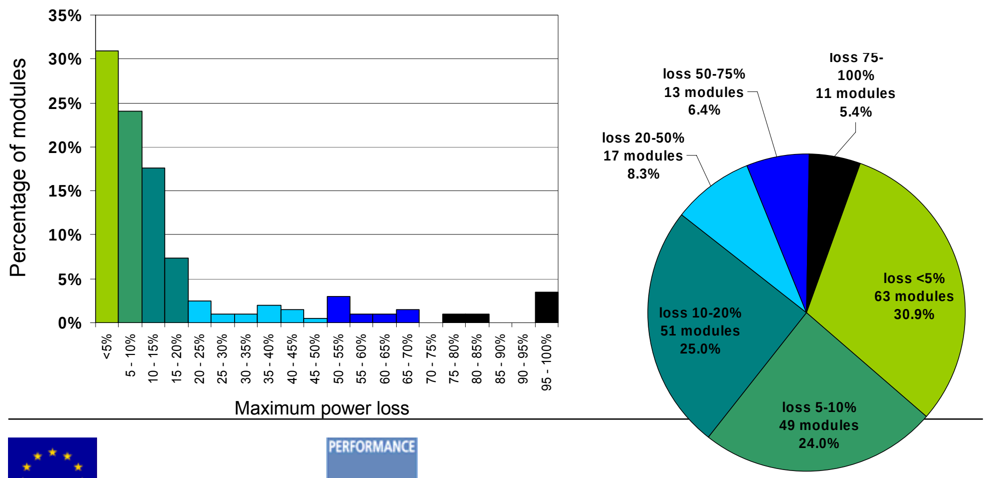
SP 5 Lifetime

Characteristics of the tested PV modules

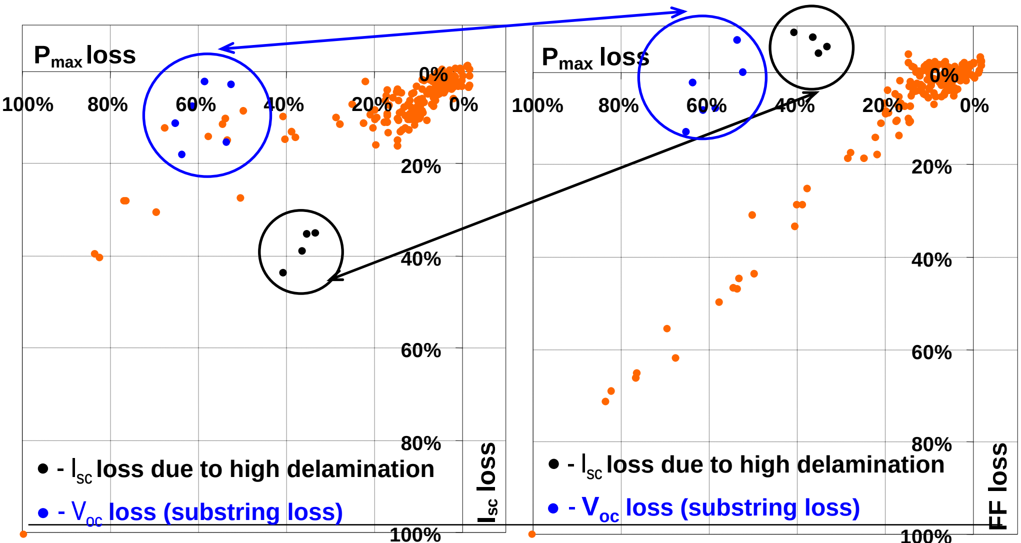
- **204 crystalline silicon-wafer based photovoltaic modules (53 module types originating from 20 different producers)**
- **Modules are rated from about 8 Wp up to 117 Wp, (average of 40 Wp)**
- **Encapsulants used: Ethylene-Vinyl Acetate (EVA) – 29 types,**
  Polyvinyl butyral (PVB) – 14 types,
  Polysiloxanes (Silicone) –8 types.
- **Back substrate used: Polyvinyl fluoride (Tedlar) – 21 cases,**
  Glass – 17 types,
  Silicone – 5 types,
  Polyester / aluminum – 4 types,
  Polyethylene – 1 type.
- **31 mono and 22 polycrystalline based cells module types (123 and 81 modules respectively)**

Overal results from electrical perfomance measurements

Histogram of P_{MAX} losses of all 204 weathered modules

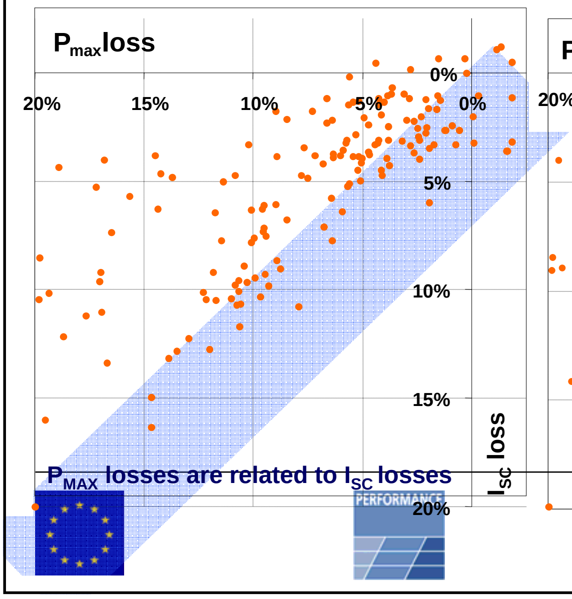


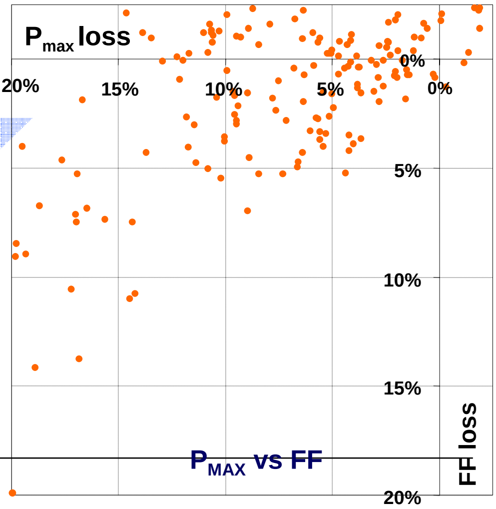
Dependance of P_{max} on I_{sc} and FF



Dependance of P_{max} on I_{sc} and FF

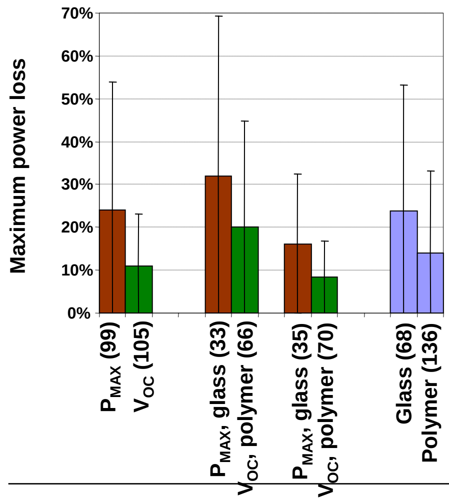
Selected modules (exibiting maximum power loss smaller than 20%)





Results from electrical performance measurements

Comparison of different type of back substrate materials and different modules conditions



The results of variance analysis (ANOVA) leads to the conclusion that:

- there is a statistically significant difference between two groups of the modules: the group connected initially to the inverter (P_{MAX}) and modules left in the open circuit (V_{OC}) conditions.
- there is also difference between groups of modules with the glass back sheet and polymer one.

Visual inspection results

The main type of visual defects observed on weathered modules

- encapsulant browning (cells area and/or the whole module front surface),
- delamination and bubbles formation in the encapsulant,
- back sheet polymer cracks,
- front surface soiling/frosting,
- blackening at the bottom edge of the module (ingrained dirt not possible to remove),
- junction box connections corrosion,
- busbar oxidation and discoloration,
- junction cables insulation degradation (modules without junction boxes),
- glass breakage (1 case of back sheet and 1 of the front surface)

PERFORMANCE

Conclusions

- High power losses (>20%) are attributed generally to FF losses (interconnections resistance increase), while moderate modules degradation is caused by I_{SC} loss due optical properties degradation and photon induced semiconductor degradation,
- There is no statistically significant difference in the performance of the modules with monocrystalline and polycrystalline cells (average degradation rate 0.7% per year),
- There is statistically significant difference between 2 groups of the modules:
  - connected initially to the inverter (average degradation 23%)
  - left in the open circuit conditions (average degradation 12%)

PERFORMANCE

Conclusions

- There is difference between groups of modules with the glass back substrate (average 23% degradation) and polymer substrate (average 14%),
- The visual appearance of field–aged modules is often not correlated with their electrical performance and state of electrical insulation,
- Of the 204 modules studied in this work 82.4% have been verified to have the final maximum power greater than 80% of the initial power i.e. meeting the manufacturers warranty criteria,
- Furthermore two thirds of modules have the final maximum power verified to be more than 90% of the initial power value after 25 years of outdoor exposure.

Performance SP6

PV as a Building Product

Project Coordinator

Berrie van Kampen

Objectives of SP6

• Providing an overview of best practices of PV applied in buildings and of the regulations and building codes in relevant EU markets.

• Determination of test procedures that are compliant with building codes and standards in the EU.

• Identification of the elements that should be contained in a PV code to be widely acceptable.

Status SP6

Available are:

- Report on Best Practices of BIPV
- Report on present regulations and PV building codes (of Netherlands, Germany, France, Switserland, Austria, Spain and Italy)
- Inventory of test requirements for CE-mark

Relevant PV-Building Concepts and Bottle-necks

PV on Water Tight Roof

Constructional Integrity
Fire Tests PV as a source of Fire
Thermal behaviour (NOCT)

PV and Roof are
to a large extent independent

Relevant PV-Building Concepts and Bottle-necks

Standard not-water tight Roof + PV Roof Tiles or Framed PV

Water Tightness and Humidity
Fire Tests PV as a source of Fire
Constructional Integrity
Thermal behaviour (NOCT)

Stakeholder Survey
Future standards development for the photovoltaic industry
Work Package 8

PERFORMANCE

Aim of the survey

- To canvass the opinion of the photovoltaic industry on areas for future standards development.

PERFORMANCE

Survey

- Designed to encourage comment
- Specific areas
- 14 questions
- 94 organisation targeted
- Telephone and e-mail

Sectors covered

Sectors	No.
Cell manufacturers	31
Crystalline silicon module manufacturers	34
Thin film module manufacturers	16
Inverter manufactures	17
Balance of system manufacturer (cabling, switch gear, connectors)	11
System suppliers and installers	29
Developers	12
Research	16
Consultants	13
Investors and financing	3

Sectors which responded
10 replies

Sectors	No.
Cell manufacturers	0
Crystalline silicon module manufacturers	3
Thin film module manufacturers	1
Inverter manufactures	0
Balance of system manufacturer (cabling, switch gear, connectors)	2
System suppliers and installers	2
Developers	3
Research	4
Consultants	4
Investors and financing	1

Areas examined

- Cell size
- Module size
- Module technologies
- DC connectors
- Performance standard

- Performance monitoring
- Calibration
- Wind loading
- Fire testing

Cell size

- 2 of 5 thought standard cells would not be beneficial
- If a standard cell should be developed should be done in conjunction with standard module size.
- Manufacturers of cell producing equipment should be consulted

Module Size

- Standard sizes would aid the building sector
- Obtaining agreement on a standard size difficult
- Need agreement between large manufacturers to have any credibility
- Standard module ratios

PERFORMANCE

Modules technology standards

- Thin film
  - Including aSi, CIS, CIGS & CdTe
- Standards should cover
  - Efficiency and overall performance
  - Diffuse radiation
  - Fluctuating power results for thin film
  - High temperature conditions, accelerated life-time testing and life expectancy, stability under real operational conditions and endurance testing
- Concentrators
- Measurement procedures specific for modules with:
  - Heat sinks, non-flat modules, BIPV and photovoltaic thermal modules

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DC Connector standard

- Conflicting opinions
  - Seen to be beneficial
  - Seen to possibly inhibit product development
- Obtaining agreement on standard design very difficult
- Potential cost reduction
- Quality standard possibly most approach

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Performance Standard

- Useful to developers and specifiers
- Must be location specific
- Development very difficult many variables
- Existing power warranties difficult to verify

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Performance monitoring standard

- General consensus was a performance monitoring standard would be beneficial
- Remote monitoring
- Life time performance monitoring
- Standard should cover
  - Monitoring equipment used
  - Sensor specifications
  - Accuracy range and stability
  - Calibration methods
  - Logging frequencies
  - Data analysis methods

Calibration and testing

- Varying opinions
  - No need for further development
  - Rather simplification
- Standards for testing solar cells and modules in the fabrication phase for classifying with respect to power output
- Specific standards for equipment e.g. flash testers and lamps and I–V curve tracing equipment

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Wind loading & Fire Testing

- General consensus is a wind loading and fire testing standard would be valuable.
- There is a need to account for varying wind speeds across Europe.
- Fire testing standard in particular for building integrated systems

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Others Standards

- DC cable colour coding
  - 3 appropriate
  - 1 added cost
  - Colour blind consideration
- European wide labelling standard

- Who would be most appropriate to develop these new standards?
  - **IEC**
  - **CENELEC**
  - **Co-operation of industry**

Summary

- There is a need for future standards development
- Areas for more immediate potential development
  - Thin film technologies
  - Performance monitoring
  - Wind loading
  - Fire testing

European Commission

EUR 23281 EN – Joint Research Centre – Institute for Energy
Title: Proceedings of the 3rd International Workshop "Thin Films in the Photovoltaic Industry"
Editor: A. Jäger-Waldau
Luxembourg: Office for Official Publications of the European Communities
2008 – 241 pp. – 21 x 29.7 cm
EUR – Scientific and Technical Research series – ISSN 1018-5593
ISBN 978-92-79-08715-8
DOI 10.2790/1269

Abstract

In the past years, the yearly world market growth rate for Photovoltaics was an average of more than 40%, which makes it one of the fastest growing industries at present. Business analysts predict the market volume to increase to € 40 billion in 2010 and expect rising profit margins and lower prices for consumers at the same time.

Today PV is still dominated by wafer based Crystalline Silicon Technology as the “working horse” in the global market, but thin films are gaining market shares. For 2007 around 12% are expected. The current silicon shortage and high demand has kept prices higher than anticipated from the learning curve experience and has widened the windows of opportunities for thin film solar modules. Current production capacity estimates for thin films vary between 3 and 6 GW in 2010, representing a 20% market share for these technologies.

Despite the higher growth rates for thin film technologies compared with the industry average, Thin Film Photovoltaic Technologies are still facing a number of challenges to maintain this growth and increase market shares.

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